PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR TRAJECTORIES IN MIDDLE CHILDHOOD, AND THE ASSOCIATION OF THESE WITH ADIPOSITY

by

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ABSTRACT

Background: The prevalence of overweight/obesity increases substantially throughout the middle childhood years. The contribution of physical activity and sedentary behaviour to the development of overweight/obesity is unclear. It is also unknown whether the impacts of physical activity and sedentary behaviour on weight differ by sex.

Purpose: To assess changes in physical activity and sedentary behaviour between the ages of 5-6 and 8-9 years, and the association of these changes with adiposity.

Methods: Longitudinal investigation using an ethnically diverse sample of 1467 children. Separate multilevel linear regression models were constructed with the change in each physical activity/sedentary behaviour measure as the explanatory and follow-up adiposity as the outcome variable.

Results: Physical activity decreased throughout the study period, whilst sedentary time increased. A decrease in moderate-vigorous physical activity (MVPA) was associated with an increase in all adiposity measures in the overall sample and in girls. An increase in TV viewing time was associated with an increase in BMI z-score in the overall sample.

Conclusion: Preventing the decline in MVPA and the increase in TV viewing time during middle childhood could reduce the incidence of overweight/obesity in this age group.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BF%	Percentage Body Fat
BMI	Body Mass Index
CI	Confidence Interval
CT	Computed Tomography
DLW	Doubly Labelled Water
DXA	Dual Energy X-Ray Absorptiometry
Hrs	Hours
HSE	Health Survey for England
IMD	Index of Multiple Deprivation
Kg	Kilogram
kJ	Kilojoule
LSOA	Lower Super Output Area
M	Metre
MET	Metabolic Equivalent
Mins	Minutes
Mph	Miles Per Hour
MRI	Magnetic Resonance Imaging
MVPA	Moderate-Vigorous Physical Activity
NCMP	National Child Measurement Programme
PAEE	Physical Activity-related Energy Expenditure
R	Correlation Coefficient
SD	Standard Deviation
SE	Standard Error
TEE	Total Energy Expenditure
TV	Television
UK	United Kingdom
USA	United States of America
WAVES	West Midlands ActiVe lifestyle and healthy Eating in School children
WC	Waist Circumference
WHO	World Health Organisation

CHAPTER 1: INTRODUCTION

1.1 Physical activity

Physical activity is defined as any movement of the body resulting in the expenditure of energy(1). Throughout this thesis, different intensities of physical activity will be referred to. Intensity can be determined by the rate of energy expenditure for a given activity. In lay terms, this refers to how hard an individual is working. Intensity is sometimes measured in Metabolic Equivalents (METs), where an individual's resting/baseline metabolic rate is 1.0 MET(2). Intensity can then be determined by the number of multiples of the baseline MET an activity produces. For example, vigorous activity includes running and climbing and is defined as an activity that produces a significant increase in heart rate and a MET greater than 6.0. Moderate physical activity produces a noticeable increase in heart rate and is between 3.0-6.0 METs. Moderate activities would include brisk walking and housework. Finally, light physical activity includes activities such as slow walking and cooking. It refers to energy expenditure at the rate of 1.6-2.9 METs(3).

1.1.1 The benefits of physical activity

The associations between physical activity with various beneficial health outcomes have been well documented in the literature. In children, a high level of moderate-vigorous physical activity (MVPA) has been found to be linked with reduced blood pressure, reduced risk of metabolic syndrome, improved bone mineral density and a lower risk of depression(4). Furthermore, school children who participate in regular physical activity, have been shown to have improved attention, academic achievement and attitude(5). The benefits of physical activity are also seen in adulthood. Higher levels of physical activity in adulthood are associated with lower risk of many diseases, including stroke, type 2 diabetes and cardiovascular disease(6-10). Obesity and overweight are further risk factors that have been linked to individuals who do not participate in the recommended amount of physical activity. Due to the fact that this association is one of the main focuses of this thesis, a detailed literature review into the relationship between physical activity and overweight/obesity in children is presented later in this chapter (Section 0).

1.1.2 Physical activity recommendations

Current United Kingdom (UK) national guidelines often refer to vigorous physical activity and moderate physical activity together as MVPA. These guidelines state that children aged 5-15 years should be participating in at least 60 minutes of MVPA per day(2,11). On at least three days each week, vigorous physical activity, which should include muscle and bone strengthening exercises, should be carried out(2,12). For children under the age of 5 years, UK guidelines recommend that once a child can stand unaided, they should be undergoing 180 minutes of activity each day(13). This should be spread regularly throughout the day. These UK recommendations match the international physical activity guidelines, developed by the World Health Organisation (WHO)(14). Other developed countries, such as the United States of America (USA) and Canada also share these guidelines(15,16).

The recommendation that children should participate in at least 60 minutes of MVPA per day was based on findings from previous literature which found that there is a dose-response relationship between the amount of MVPA that a child carries out, and indicators of cardiovascular and metabolic health(15,17). It has been shown that most of these health benefits occur by carrying out 60 minutes of MVPA per day, and that this should be enough to maintain a healthy cardiovascular and metabolic health profile(17).

Physical activity in excess of 60 minutes per day, is likely to produce additional health benefits, although research into this is limited(14).

1.1.3 Physical activity levels among children in the UK

The Health Survey for England (HSE) is an annually conducted survey of a nationally representative sample of approximately 6000 households, enquiring about health and lifestyle. Each year a core set of questions is asked in order to gather information about general health. In addition, every year there is a focus on one further area of health. The focus between 2008 and 2012 was physical activity and fitness. These were assessed with the use of a validated questionnaire(18). HSE findings from 2012 showed that between the ages of 5-15 years, most children do not meet the government's recommendations of ≥60 minutes of MVPA per day; just 16% of girls and 21% of boys met the recommendations(18).

1.1.4 Variations in physical activity by socio-demographic subgroup

The HSE 2012 did not find any significant association between the proportion of children meeting the UK's physical activity recommendations and household income(18). Other studies that have researched differences in the physical activity levels of children by socioeconomic status did not find any significant differences in boys, but found that girls from lower socioeconomic groups were significantly less active than those from higher socioeconomic groups(19).

The Child Heart and Health Study in England (CHASE) study objectively measured and compared the physical activity levels of children of different ethnic groups in the UK at age 9-10 years(20). It discovered that South Asian children carried out the least physical activity compared with White British and African-Caribbean children. A further study looking at ethnic variation in physical activity, discovered that White adolescent girls have higher MVPA levels than Black African-Caribbean girls. By contrast, in boys, no differences in MVPA levels between these two ethnic groups were identified(19).

1.2 Sedentary behaviour

Sedentary behaviour is defined as any activity that does not substantially increase energy expenditure above the baseline/resting level(21). Activities such as television (TV) viewing, sleeping and sitting are examples of sedentary activity. These behaviours generally produce energy expenditure at the level of 1.0-1.5 METs(21). It is vital to note that sedentary behaviour is not simply the absence of physical activity. It has previously been thought that when an individual engages in sedentary behaviour, they are limiting their time available to participate in physical activity. This has been known as the displacement hypothesis(22). However, it is now realised that individuals can meet physical activity guidelines, but still spend too long being sedentary(23). Furthermore, a meta-analysis conducted on adolescents and children, discovered only a small negative association between physical activity and sedentary behaviour(24). Therefore, physical activity and sedentary behaviour need to be considered as separate variables and their independent associations with overweight/obesity assessed.

1.2.1 The health risks of sedentary behaviour

The risk associated with spending too long participating in sedentary behaviour is a growing area of research. One important consideration is how sedentary behaviour is assessed, as some studies misclassify this as any time not spent in MVPA (thus also including light physical activity)(3), whilst others use proxy measures of sedentary behaviour (typically TV viewing time), which may not fully represent sedentary time. Despite the limitations in measurement, sedentary behaviour, independent of physical activity, has been associated with many diseases and adverse health outcomes in both children(25,26) and adults(27-29). These include metabolic syndrome(26,28), type 2 diabetes(27), cardiovascular disease(29) and low self-esteem(25). Excess sedentary behaviour is considered to be one of the top five causes of mortality worldwide(30).

1.2.2 Sedentary behaviour recommendations

The UK activity guidelines were revised in 2011. For the first time, recommendations regarding sedentary behaviour were included. However, this guidance is rather vague and simply recommends that children aged 5-18 years 'minimise the amount of time spent being sedentary for extended periods'(2). Insufficient evidence was stated as the reason for why a time limit on sedentary behaviour had not been provided. In the USA, guidance regarding sedentary behaviour refers only to screen time and recommends that children carry out no more than 2 hours of screen time each day(31,32).

1.2.3 Sedentary behaviour among children in the UK

The HSE 2012 measured the total sedentary time of English children outside of school hours with the use of a validated questionnaire(18). It estimated sedentary time by combining the time spent watching TV with various other sedentary activities (computer and video-game use, drawing, homework and reading). It found that the mean total sedentary time for boys and girls was similar (3.3 hours and 3.2 hours respectively on week days; and 4.2 hours and 4.0 hours respectively on weekend days). Approximately

50% of total sedentary time was accounted for by TV viewing, with boys watching 1.7 hours and 2.2 hours of TV on week days and weekends respectively; and girls watching 1.6 hours and 2.2 hours on week days and weekends respectively.

1.2.4 Variations in sedentary behaviour by socio-demographic subgroup

In terms of subgroup variations in sedentary behaviour patterns, children from the lowest socioeconomic group were found in the HSE 2012, to watch more TV compared to those in the highest socioeconomic group(18). This difference was particularly marked on weekends, where boys and girls in the highest socioeconomic group watched 1.8 hours and 2.0 hours respectively, whereas the equivalent figures in the lowest socioeconomic group were 2.4 hours for both genders(18). Ethnic variation in the sedentary activity of UK children is a rather neglected area of research. The very limited research that has been conducted suggests that Black children are more sedentary than their White and Asian counterparts(19).

1.3 The importance of overweight and obesity

The worldwide prevalence of childhood overweight and obesity has increased in recent decades(33,34). Globally, it is now estimated to affect 170 million children(35). The overweight/obesity prevalence in the UK has been no exception to this international trend(36,37). Currently, approximately 20% of UK children are obese when they leave primary school(38). Despite the fact that most of the adverse health consequences of being overweight/obese only appear during adulthood, there is evidence that obese children can suffer from health conditions such as sleep apnoea and type 2 diabetes(39). In addition, the Bogalusa Heart Study found that children whose Body Mass Index (BMI) is at or above the 85^{th} percentile for their age, have higher total cholesterol, blood pressure and fasting insulin levels(40). There are also adverse psychological effects of being an overweight child. The incidence of depression and poor self-esteem are higher compared to those of a healthy weight(35). There is consistent and strong evidence that childhood obesity tracks into adulthood(41-45). A large retrospective cohort study in the USA discovered that 69% of children that were classified as very obese between the ages of 6 to 9 years, maintained this obesity into young adulthood (defined as between 21-29 years of age)(46). Obesity is also an important contributor to premature mortality, with 5% of all deaths worldwide being directly attributed to obesity(30). This is because obese adults are at higher risk of a number of diseases, such as stroke, type 2 diabetes, cardiovascular disease and many forms of cancer (including kidney, breast and colonic cancers)(47).

1.3.1 The epidemiology of overweight and obesity in children in the UK

For over a decade, childhood overweight/obesity has been one of the UK's key public health issues. This thesis focuses on children in the middle childhood years (generally considered to be between the ages of 5 to 9 years)(48). The National Child Measurement Programme (NCMP) annually collects anthropometric data from children from English state schools when they are in reception (age 4-5 years) and in year 6 (age 10-11 years)(38). Between 2006 and 2015 the NCMP consistently demonstrated, that as children move through middle childhood, there is a rapid rise in overweight/obesity prevalence(38,49-51). In the 2014/15 academic year, the prevalence was shown to be 21.9% (9.1% obese, 12.8% overweight) at age 4-5 years, and 33.2% (19.1% obese, 14.1% overweight) among children aged 10-11 years(38). It is therefore vital to further our understanding of the development of overweight/obesity in children in this age group, in order to inform interventions that may prevent this significant increase in obesity levels during the middle childhood years.

1.3.2 Variations in overweight/obesity prevalence by socio-demographic subgroup

In children in the UK, overweight/obesity prevalence differs by socioeconomic and ethnic groups, and by gender. There is a strong positive relationship between the level of deprivation and obesity prevalence(38,51). The gradient is such that when children in the NCMP were categorised into deprivation quintiles using the Index of Multiple Deprivation (IMD) 2010, those in the most deprived quintile had double the obesity prevalence of those in the least deprived(38).

In terms of ethnic variation, at age 4-5 years, Black African children have the highest prevalence of obesity(51). Obesity prevalence is also higher than the national average in Asian and Mixed ethnic groups(38). In contrast, White British children tend to maintain an obesity prevalence that is lower than the national average whilst they are at primary school(38).

Based on data from NCMP 2014/15, boys have higher levels of obesity compared to girls. At age 4-5 years, 9.5% of boys were obese versus 8.7% of girls. The gap widens such that the prevalence is 20.7% for boys aged 10-11 years and 17.4% for girls of the same age(38).

These subgroup variations in the overweight/obesity prevalence of children must be taken into account when designing and conducting any childhood overweight/obesity research. This is so that the appropriate covariates are adjusted for during analysis and so that findings are not over-extrapolated to demographic groups that were not well represented in the study's population.

1.4 Detailed literature review

Having discussed above the epidemiology and health effects of physical activity, sedentary behaviour and obesity, this section includes a more detailed literature review of four themes that are particularly relevant to this thesis: a) Changes in physical activity and sedentary behaviour during childhood; b) tracking of physical activity and sedentary behaviour in children; c) the association between physical activity, and adiposity in children; and d) the association between sedentary behaviour, and adiposity in children.

1.4.1 Research examining changes in physical activity and sedentary behaviour during childhood

Many of the previous studies aiming to examine changes in physical activity and sedentary behaviour with age, have been cross-sectional in nature(19,52). The HSE 2012 found that the percentage of children meeting the UK's physical activity targets decreases as the children get older(18). In the 5-7 years age group, 24% of boys were meeting the recommendations compared to just 14% of boys at age 13-15 years. In girls, the proportion reduced from 23% to 8%. The HSE also found that the mean total sedentary time per day increased in children between these age groups. On week days it increased from 2.7 hours to 4.3 hours and on weekends from 3.9 hours to 5.1 hours(18). However, this cross-sectional method of assessing change over time has many limitations. Firstly, cross-sectional studies are unable to account for secular trends that influence the physical activity and sedentary behaviour of children of all ages at a particular point in time(19). Secondly, cross-sectional studies are unable to account for differences in the individual characteristics of the children measured, which may have an impact on their physical activity and sedentary behaviour levels.

The few longitudinal studies that have been undertaken have focused on the changes throughout the adolescent and older childhood years(19,53-58). In addition, some studies have included only female participants(56,58). The results of these studies have consistently found that as children get older, their MVPA levels decrease and their total sedentary time increases(19,48,52-55,57-59). Mitchell et al examined the changes in the levels of sedentary behaviour objectively and longitudinally using growth curve analysis, from ages 12 to 16 years(53). It was discovered that between these ages, the total sedentary time of girls increases at a rate of 23 minutes/day/year and that of boys increases by 20 minutes/day/year. Furthermore, a study looking at physical activity levels concluded that throughout the school years, physical activity declines at a rate of 7.4% per year for girls, and a rate of 2.7% for boys(59). An important finding from the studies with older children, is that their baseline measures of physical activity and sedentary behaviour were already at undesirable levels(53,54). This means that younger children must now be examined, in order to determine exactly when the majority of children stop meeting the recommendations for physical activity and sedentary behaviour.

Most of the studies including both boys and girls, have conducted their analyses separately by gender. However, it is so far inconclusive as to whether changes in physical activity and sedentary behaviour differ between boys and girls(57). More studies have found that the rate of decline in physical activity and the rate of increase in sedentary behaviour is greater in girls than in boys(19,52,53,59). However, there are studies that have found similar rates of change(48,60) and two that reported a greater decrease in MVPA in boys(54,57). One author argues that previous literature suggests that the MVPA of girls declines more during childhood, and that of boys declines more in adolescence(54).

Comparison of the changes in physical activity and sedentary behaviour throughout childhood between different ethnic groups, socioeconomic groups and by weight status have very rarely been considered. Three studies did consider ethnic variations(19,55,58). All three of these studies measured physical activity and sedentary behaviour with the use of a validated questionnaire. One of these studies followed 2379 girls (1166 White and 1213 Black) in the USA between the ages of 9-10 years and 18-19 years(58). It had a high follow-up rate of 89% and there were no discrepancies between ethnic groups in terms of follow-up, education and family income. It found that the physical activity levels of Black girls decreased at a faster rate than White girls. A further study, conducted in London, UK, examined a sample of 5863 children (64% White, 24% Black, 10% Asian and 2% other) between the ages of 11-12 years and 15-16 years. Sampling was conducted in order to obtain a representative sample of children in London. It found little difference in the rate of change in physical activity and sedentary behaviour between the various ethnic and socioeconomic groups(19). However, its conclusion was that there were already differences in the levels of physical activity and sedentary behaviour between ethnic and socioeconomic groups at baseline (11-12 years), and therefore more research with younger children is needed to determine exactly when these differences emerge. At baseline, the lowest physical activity levels were seen in Asian children and the highest sedentary time was found in Black children. The third study was conducted using a nationally representative sample of 13000 children in the USA(55). The ages of children at baseline varied between 11-21 years, and at follow-up between 18-26 years. It found that Black females were more likely than White females to maintain desirable levels of MVPA between these ages. Furthermore, black children of both genders were more likely to maintain high levels of screen time compared to White children. This finding is in contrast to the study conducted in London. This could be caused by there being different factors which influence physical activity and sedentary behaviour in the UK compared with the USA. Limited research on variations in activity levels between children of different weight status has been conducted. The very small number of published research papers on this topic suggest that the rate of decline of MVPA throughout childhood in overweight/obese children is similar to that seen in their normal weight counterparts(54).

1.4.2 Research examining the tracking of physical activity and sedentary behaviour throughout childhood

Tracking is defined as the maintenance of an individual's relative rank within an age-sex cohort over a period of time(61). The tracking of physical activity and sedentary behaviour in childhood is an important area to research. If there is a high level of tracking, then early intervention programmes can be used to establish healthy levels of physical activity and sedentary behaviour that an individual is able to maintain over a prolonged period of time. Previous studies researching the tracking of physical activity and sedentary behaviour have tended to focus on children older than the middle childhood years.

A systematic review of the tracking of sedentary behaviour from childhood to adolescence found that sedentary behaviour tracks at moderate levels, and TV viewing in particular tracks more than other forms of sedentary behaviour, such as computer and electronic game use(62). Another study from the UK of 14500 children aged 12 years at baseline, found that the likelihood of being in the most sedentary quartile at follow-up (aged 16 years) was two times as likely among those who were in the most sedentary quartile at baseline(53). This suggests that there is a group of children who maintain high levels of sedentary behaviour.

Physical activity has generally been found to track less through childhood(48,61,63). However, one investigation examining girls only, found that participants in either the most active or the least active quintile of MVPA at age 12 years were three-times more likely to remain in their quintile at age 14 years than move to any other MVPA quintile(56). Interestingly, in this study there was a lot more movement of participants between the middle three quintiles from baseline to follow-up, compared with movement out of the least active and most active quintiles.

Difference in the tracking of activity behaviours between boys and girls have been looked at in some studies(53,61,62), but with no consistent findings.

1.4.3 Research examining the association between physical activity, and overweight/obesity in childhood

Intuitively, one would expect an inverse association between the amount of physical activity and risk of excess weight in children(64). However, the individual, relative effects that both energy intake and energy expenditure have on body weight in children are still unknown(65).

The results of studies focusing on the association between physical activity and overweight/obesity have been rather mixed and inconclusive. A small number of reviews have aimed to draw conclusions from the body of research on this topic(66-70). Some of the earlier reviews, by default, had to include older studies which rarely used an objective measure of physical activity. Furthermore, most of these older studies are cross-sectional. In 2005, Must and Tybor concluded in their review that results from previous studies had been inconsistent, but on balance physical activity probably had a protective effect against weight gain throughout childhood(66). Other systematic reviews at the time came to similar conclusions(68,69). More recently there have been two reviews which have had contrasting conclusions to each other. In 2010, Jiménez-Pavón et al examined cross-sectional and longitudinal studies which had been conducted between 2004 and 2008, and had used an objective measure of physical activity(70). Studies that included children from 0-18 years were included. 79% of included studies found a significant negative relationship between physical activity and the measure of adiposity used. In contrast, in 2011 Sijtsma looked at cross-sectional and longitudinal studies that had assessed physical activity either objectively or by direct observation(67). This review included children of a younger age (between 1.5-6 years at baseline). Its conclusion was that there is not enough evidence to confirm an association between physical activity and overweight/obesity in children, and that more research in this area is required. Just 5 out of 17 studies included in this review found an inverse association between physical activity and weight(48,71-74). Furthermore, the HSE 2012 compared the number of overweight/obese children meeting UK activity guidelines with those who were a healthy weight. No significant differences were found(18).

A recent advancement in this area of research is a movement towards examining the separate associations between the different levels of intensity of physical activity, and overweight/obesity. When physical activity is objectively measured, the time spent in the different subcomponents of physical activity can be obtained. This includes time spent in vigorous, moderate, moderate-vigorous and light physical activity. Total physical activity can also be obtained. Researching the subcomponents separately has more relevance to the current UK physical activity guidelines, which recommend that children undertake at least 60 minutes of MVPA per day(11). The few studies that have considered these physical activity constructs individually, have consistently found that the time spent in the more vigorous subcomponents of physical activity has a stronger association with adiposity, compared with total physical activity and lighter forms of physical activity(48,75-78). This has been found both cross-sectionally and longitudinally, and suggests that future studies should either focus on the more vigorous forms of physical activity or examine the effect of the different levels of intensity separately.

A recent review found that the association between physical activity and weight highly depended on the measure of adiposity used in each study(67). In this review, 60% (3/5) of included studies that used percentage body fat (BF%) as the outcome measure found a significant inverse relationship, compared with just 18% (2/11) of those that used BMI or BMI z-score. The population included in this review consisted of young children (mostly preschool age)(67). BMI is a very common method to determine the presence of overweight and obesity. However, it is determined by two separate components: fat mass and lean mass. These may have differing influences on health. In addition, when BMI is used, some children are incorrectly labelled as overweight or obese due to possessing a relatively large muscle mass(79,80). To date, most studies have used a proxy for adiposity, such as BMI, as the outcome of interest(70). It is vital that future work includes a range of adiposity measures, in order to increase the validity of the results.

Very few studies researching the association between physical activity and weight status in children have considered differences in the association between boys and girls(67,70). For example, it was noted in the Sijtsma review that just 3 out of 17 of the included investigations carried out their analyses separately by gender(72,73,81). The very small number of studies that have explored gender differences suggest that there may be a stronger inverse association between physical activity and weight in boys compared with girls(70). This is due to significant and stronger associations being found slightly more frequently in boys. A recent longitudinal study from the UK, which used the change in accelerometer-determined MVPA between the ages of 7-9 years as the exposure variable, found that a decrease in MVPA was associated with an increased fat mass index and BMI z-score in boys, but not in girls(77).

1.4.4 Research examining the association between sedentary behaviour, and overweight/obesity in childhood

Four reviews summarise the rather limited body of research on the association between sedentary behaviour and adiposity in children(66,82-84). Similar to physical activity research, results are inconsistent and vary according to how sedentary behaviour was assessed. Subjective measures of sedentary behaviour, based on questionnaires completed by the children or their parents, were included in reviews carried out by Must and Tybor(66) and Rey-López et al(82). On balance, these two reviews found positive associations between sedentary behaviour and adiposity. The systematic review by Must and Tybor(66) included nine prospective observational studies on children under 10 years of age, examining the relationship between sedentary behaviour and overweight/obesity levels(85-93). Six of these studies found positive associations(86,89-93), whilst the other three did not find any statistically significant associations(85,87,88). Furthermore, a meta-analysis consisting of 39 studies on children aged 3-18 years obtained a small but significant relationship between the time spent watching TV and body fatness (Pearson r=0.066, 95%CI=0.056, 0.078)(83). However, the authors proposed that this small effect size was unlikely to be clinically relevant.

In contrast, studies using objective measurements of total sedentary time have had very different findings. The 2014 systematic review by Tanaka et al only included longitudinal studies that examined the association between changes in objectively measured sedentary behaviour and changes in adiposity(84). No specific adiposity measure was required. Only three studies meeting these criteria were found(77,94,95), and overall there was little evidence to suggest that a positive relationship between sedentary behaviour and adiposity in children is present(84), with only one of the three studies reporting a significant positive association(94). In this particular study, sedentary behaviour was only associated with a significantly increased BMI in children who, at baseline, had a BMI at the 50th percentile or higher. No relationship was found in children at the 25th or 10th BMI percentiles(94). This suggests that associations may differ by a child's weight status.

The main challenge with researching the impacts of sedentary behaviour is that although objective measures provide the most accurate data, these measures cannot quantify the amount of time spent participating in the various types of sedentary behaviour (e.g. TV viewing, video-gaming, homework, computer use). These various activities may have differing impacts on adiposity(82), through differential effects on resting metabolic rate and complex associations with other obesogenic behaviours, and thus ideally need to be investigated separately. To date, when subjective measures of sedentary behaviour have been used in studies, TV viewing time has been the primary variable investigated(82). The majority of these studies have reported a positive association between TV viewing time and weight in children(66,82). An Australian study concluded that, after adjustment for confounding factors, for each additional hour of TV watched at the age of 6 years, there was a 40% increased odds of being overweight at the age of 8 years(89). The American Academy of Paediatrics recommend that children should watch no more than 2 hours of TV per day(31,32). One study which examined girls exclusively, found that girls who repeatedly exceeded these American TV viewing recommendations between the ages of 7 and 11, were 13 times as likely to be overweight at age 11, compared with girls who never exceeded this 2 hour per day limit(96). Other sedentary behaviours are underrepresented in current research. In contrast to the research on TV viewing, the very limited studies examining video-gaming and computer use, have almost always found a null relationship(82).

Gender differences in associations between sedentary behaviour and adiposity have rarely been considered. Three cross-sectional(97-99) and two longitudinal studies(90,92) examining the association of TV viewing duration and adiposity in children under the age of 10 years reported significant positive associations in girls and not boys. However, more research is required to address conclusively whether gender differences exist.

1.5 Summary

Current research examining the association between physical activity and sedentary behaviour, and overweight/obesity in children has produced mixed, inconclusive results. Studies exploring the change in physical activity and sedentary behaviour over time have shown that as children get older they become more sedentary and their physical activity levels decrease. However, most of this research has been conducted with older children whose physical activity and sedentary behaviour levels were already at undesirable levels at baseline. Longitudinal research on younger children (in the middle childhood years), that uses an objective measure of physical activity and total sedentary time, in addition to examining different sedentary behaviours separately, is needed.

Before future intervention programmes aiming to reduce childhood overweight/obesity through targeting physical activity and sedentary behaviour levels are designed, the following questions need answering:

1) Is there a significant association between physical activity and sedentary behaviour, and overweight/obesity in children? In other words, is intervening with these behaviours likely to achieve the goal of reducing overweight/obesity prevalence?
2) When is the best time in childhood to target these behaviours? Ideally, this would be before physical activity levels drop below the recommended levels and sedentary behaviour levels increase above recommended limits.

3) How do these behaviours track throughout middle childhood? This is important in order to determine whether any changes in physical activity and sedentary behaviour that are made by intervention programmes are likely to be maintained over time. If these behaviours track at low levels, the programme is unlikely to be cost-effective and to achieve its long-term goal.

By aiming to answer the above questions, this thesis contributes to the evidence required for the development of future intervention programmes.

1.6 Aims and objectives

Thus, the aims of this study are: to determine how the levels of physical and sedentary activity change and track between the ages of 5-6 years and 8-9 years; and to explore the associations between physical activity, total sedentary time and various different types of sedentary behaviour, and adiposity in children between these ages.

The specific objectives are to:

1. Describe the levels of physical activity and the time spent undertaking sedentary activities at baseline and follow-up, in the overall sample and by gender.
2. Calculate the rate of change in physical activity and sedentary behaviour in children between the ages of 5-6 years and 8-9 years.
3. Explore the extent to which physical activity and sedentary behaviour tracks throughout the middle childhood years.
4. Explore longitudinal associations between the change in time spent undertaking physical activity and sedentary behaviours, and adiposity, measured in a range of ways, and adjusting for potential confounders.

5. Explore how the associations between physical and sedentary activity, and measures of adiposity differ by gender.

1.7 Overview of thesis

This thesis is based on longitudinal data obtained from the West Midlands ActiVe lifestyle and healthy Eating in School children (WAVES) study. The WAVES study is a large trial of childhood obesity prevention in the UK, with an ethnically and socioeconomically diverse sample of children(100), thus increasing the relevance of this study's findings to the UK's diverse population. Chapter Two describes the methodology of the research presented in this thesis. Chapter Three describes how physical activity and sedentary behaviour levels change and track at three time-points between the ages of 5-6 years and 8-9 years. In Chapter Four, the longitudinal associations between physical activity and sedentary behaviour, and adiposity are examined. Chapter Five discusses the findings overall, and presents the conclusions of the thesis.

1.8 Statement of contribution

All data that have been analysed as part of the work presented in this thesis were collected between May 2011 and March 2015 by the WAVES study's research team. The data relevant to my research were extracted from the main database by Emma Lancashire and given to me as a dataset in SPSS format. From this dataset, I created the new variables which were required to answer the research aims. I developed all of the research aims and objectives with input from my supervisors, Miranda Pallan and Peymane Adab. I developed the statistical analysis plan with some advice from a statistician (James Martin) and I conducted all statistical analysis. The interpretation of the results presented is my own interpretation after discussion with my supervisors.

CHAPTER 2: METHODOLOGY

2.1 Introduction

The two investigations outlined in this thesis both use longitudinal data collected at baseline and two follow-up time-points from the West Midlands ActiVe lifestyle and healthy Eating in School children (WAVES) study. Full details of the WAVES study can be found in the WAVES study protocol(100) and in Section 2.3 of this chapter. This chapter also outlines the method used to obtain physical activity data in the WAVES study and how this compares with other available methods and why it was chosen in preference. The procedures used to collect sedentary behaviour and anthropometric data are then described. Finally, the statistical analyses that have been conducted to meet the aims and objectives outlined in Section 1.6 are summarised.

2.2 Design

The WAVES study is a 5-year cluster-randomised controlled trial aiming to assess the clinical and cost-effectiveness of a 12-month childhood obesity prevention programme(100). For this study, I have used data from measurements taken at three time-points within the trial. As can be seen in Figure 2.1, baseline measurements were taken when children were 5-6 years old (year 1), before the intervention programme had commenced. The first follow-up measurements were taken 3 months after the completion of the 12-month intervention period, when children were aged 7-8 years (year 3). Second follow-up measurements were collected 18 months post-intervention, when children were aged 8-9 years (year 4).

2.3 The WAVES study

2.3.1 Overview

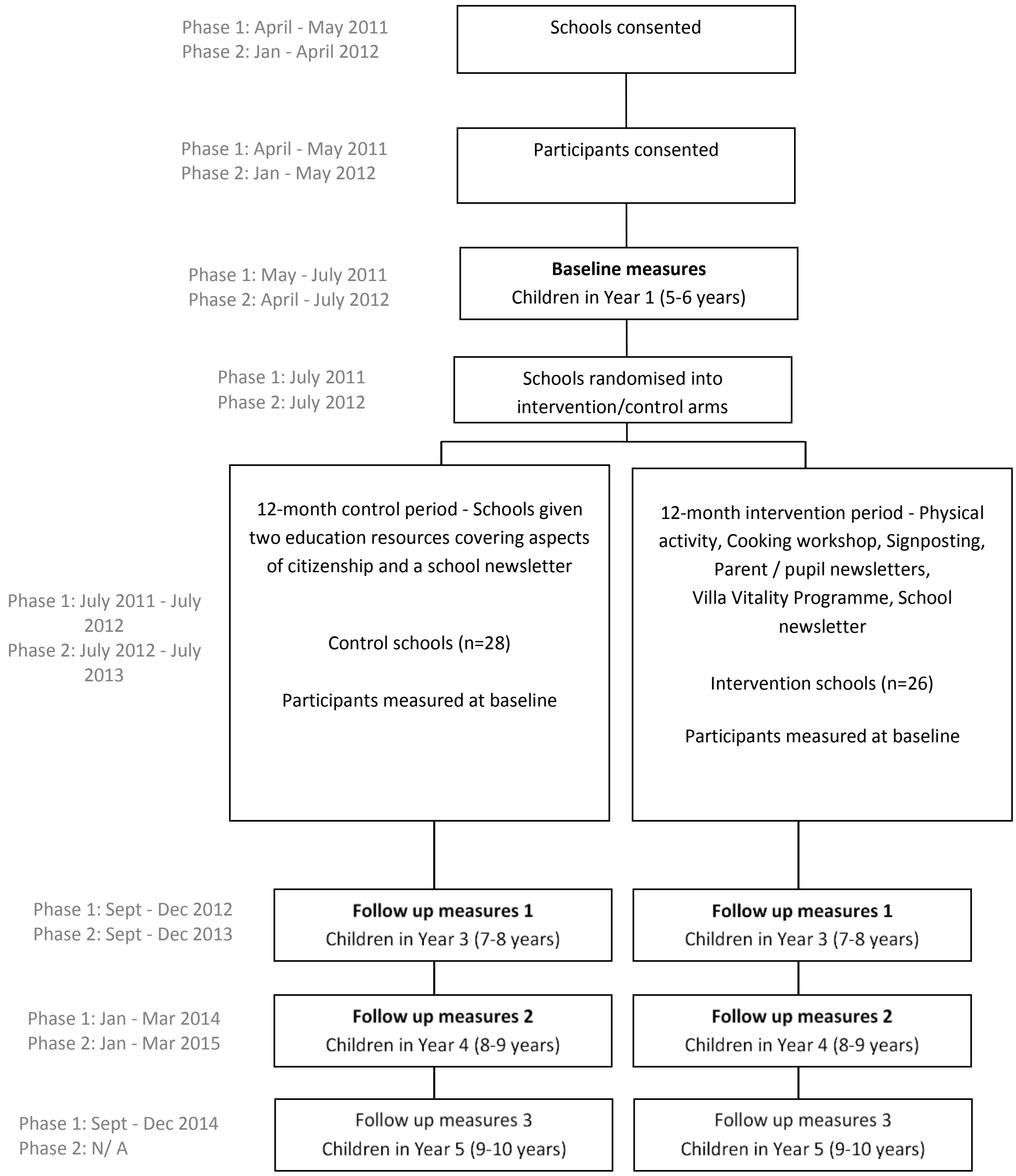
The obesity prevention intervention delivered by the WAVES study had four components which targeted physical activity and healthy eating in both the school and home environments. The four components were: (1) An increase in opportunities for physical activity within the school day; (2) cooking workshops for parents and children; (3) signposting of opportunities for physical activity outside of school; and (4) a healthy lifestyle programme run by Aston Villa Football Club.

The primary outcome of interest was the difference in BMI z-scores between the intervention and control groups at follow-up 1 and follow-up 2. Secondary outcomes included differences in the measures of physical activity between the two arms at follow-up 1 and follow-up 2.

2.3.2 The WAVES study's timeline

Practical considerations owing to the WAVES study's large sample size meant that the study was conducted in two phases, as can be seen in Figure 2.1. Baseline data collection for phase 1 schools occurred between May and July 2011. After baseline measurements were taken, random allocation of schools to intervention and control groups took place. The 12-month intervention programme was delivered whilst children were aged 6-7 years (year 2). Follow-up 1 measurements were then taken between September and December 2012 and follow-up 2 measurements between January and March 2014. Phase 2 schools followed the same measurement schedule but baseline data collection in these schools commenced in April 2012 and follow-up 2 was completed in March 2015.

Figure 2.1: Study timeline and the flow of participants through the WAVES study.



Bold font represents time-points where data used for analyses in this thesis were collected.

2.3.3 Participants

The study sample included 1467 children from 54 primary schools in the West Midlands, UK. The sampling frame consisted of all Local Authority-maintained primary schools within a 35 mile radius of the University of Birmingham. Schools were excluded if they had previously been identified as being in special measures (failing to deliver an acceptable level of education) by the Office for Standards in Education. In addition, any school with fewer than 18 pupils in year 1 was also excluded. This gave a total of 980 schools in the sampling frame. The sampling method used was chosen in order to obtain an ethnically and socioeconomically diverse sample to allow subgroup comparisons. Schools were stratified by ethnic representation in relation to the three main ethnic groups in Birmingham: White British, South Asian and Black. Weighted random sampling was conducted so that schools with a greater proportion of South Asian and Black pupils had a higher chance of selection, with a ratio of 2:2:1 (South Asian, Black, White British). Sampling was also balanced to take into account the size of the school, the urban/rural location of the school and the socioeconomic status of the pupils. The socioeconomic status of pupils was assessed using the proportion of pupils eligible for free school meals. 200 schools were selected using this sampling method. These schools were ordered using a random number generator, and sequentially invited to participate via a letter and a visit from the research team. Ninety schools declined and 4 failed to respond, meaning that 148 of the 200 schools had to be approached until the required sample size of 54 schools was obtained. Responder bias was checked to test for differences in the school size, and the ethnicity and the socioeconomic status of pupils from schools that accepted the invitation to participate compared with those that declined. No significant differences were found.

2.3.3.1 Justification of sample size

The sample size of at least 1000 pupils from 54 schools was derived based on the ability to detect a clinically important difference in BMI z-score of 0.25 between arms with 90% power(101) and allowing for a potential school drop-out rate of 8%.

2.3.4 Ethical approval and funding

The parents of children in year 1 from each participating school were sent an information leaflet and consent form. Written parental consent was obtained and on each day of data collection, verbal assent was given by each child before measurements were taken. Data were stored in a password-protected database. Hard copies of data collection sheets were locked in the research team's office. Ethical approval for the WAVES study was gained in April 2011 from the Black Country NHS Research Ethics Committee (NHS REC no.10/H1202/69, ISRCTN:97000586). The study was funded by the National Institute for Health's Health Technology Assessment Programme.

2.4 Study measurements

At baseline and each follow-up time-point, a number of measurements were taken from each child whilst they were at school. These included anthropometric, dietary and psychological measurements. Data were collected by trained researchers who followed standardised procedures and used validated instruments. The researchers also fitted children with Actiheart monitors (see Section 2.5.1), which they were instructed to wear continuously for five days, to monitor their physical activity levels. Furthermore, parents were requested to complete a parental questionnaire at baseline and each follow-up time-point. The questionnaire included questions regarding the child, and wider family's demographics, physical activity, sedentary behaviour, sleep habits, food habits and the local environment.

2.5 Measurement of physical activity

Two physical activity variables have been used for the analyses presented in this thesis:

- Average number of minutes of MVPA per day.
- Physical Activity-related Energy Expenditure (PAEE) (kJ/Kg/day). This has been used as a measure of the total physical activity per day.

These measurements were obtained objectively using the Actiheart monitor (Actiheart, Cambridge Neurotechnology Ltd, Papworth, UK).

2.5.1 Actiheart

The Actiheart was the first commercially available combined heart rate monitor and accelerometer. It has been validated in children (aged 12 years)(102) and has proven technical reliability(103). The monitor is attached to the chest via electrodes so no chest strap is needed. It is also waterproof meaning that it does not need to be removed whilst showering. In the WAVES study, children were fitted with the Actiheart monitor on Wednesday, Thursday or Friday and instructed to wear the monitor for five continuous days. This was done so that children had physical activity data for three week days and two weekend days.

Heart rate and acceleration data were recorded in 30 second epochs. Adult studies usually capture data in 60 second epochs. However, children have more varied and intermittent patterns of activity(104,105) and so shorter epoch lengths for children help to capture this more accurately(106).

The Actiheart measures body acceleration in counts. Count is an arbitrary unit that varies between different accelerometer models. In order to allow comparison of results with other studies that used different accelerometers, it is therefore beneficial to convert the counts into the SI unit of metres per second squared (m/s^2)(107-109). The Actiheart data were processed and converted into m/s^2 using a conversion factor of 0.003(103). This was carried out by the Medical Research Council Epidemiology Unit at the University of Cambridge. Previously defined cut-offs for vertical acceleration were used to define physical activity levels as: Light Physical Activity (>0.75 m/s^2 and ≤1.75 m/s^2), Moderate Physical Activity (>1.75 m/s^2 and ≤5.0 m/s^2) and Vigorous Physical Activity (>5.0 m/s^2)(102). The time spent in minutes in each of these subcomponents of physical activity was calculated. Moderate Physical Activity and Vigorous Physical Activity were combined to give the number of minutes spent in MVPA each day. MVPA was chosen as one of the physical activity variables in this study because the UK guidelines are based on MVPA(11) and to allow easier comparison with the results from previous studies.

The values of the PAEE variable were derived using the combined heart rate and acceleration data. PAEE estimates total energy expenditure from physical activity per day. In this sense, PAEE is a measure of total physical activity. PAEE was calculated using regression analysis provided by the Actiheart software (Camntech, Cambridge, UK). The regression equations were based on group calibration of the children’s heart rate and oxygen consumption (VO_2). Previous research has consistently found that combined heart rate and motion monitors provide superior accuracy of PAEE estimates compared with using heart rate monitors or accelerometers alone (110-115).

A child's physical activity data were only included in analysis if he/she had provided a minimum of 24 hours of recorded data. To provide representation of the entire 24 hour period and reduce diurnal bias, this had to be dispersed as a minimum of 6 hours in each quadrant of the day across the 5 day measurement period(116). Quadrants were defined as: 3am-9am; 9am-3pm; 3pm-9pm and 9pm-3am. In addition, non-wear time was removed. This was assumed if there had been an acceleration of zero and an implausible heart rate for 90 consecutive minutes or more.

2.5.2 Comparison with other methods of measuring free-living physical activity

2.5.2.1 Objective methods

2.5.2.1.1 Doubly Labelled Water

Doubly Labelled Water (DLW) is the gold standard method of measuring free-living total energy expenditure (TEE). Participants are given a known volume of water to ingest which is labelled with the non-radioactive isotopes ^{2}H (deuterium) and ^{18}O (oxygen-18). Samples of blood, urine or saliva are then taken over the next 5-14 days. ^{2}H is eliminated as water whilst ^{18}O is eliminated as water and carbon dioxide. The difference between these two elimination rates therefore determines the carbon dioxide formation rate, which is a measure of TEE(117). TEE can then be used to calculate energy expenditure from physical activity by subtracting an individual's basal metabolic rate and the thermogenesis induced from food consumption(117,118).

Despite the fact that this method accurately determines TEE, a poor estimation of an individual's basal metabolic rate would give an inaccurate PAEE(119). The requirement for multiple biological samples makes this method unfeasible for a large scale epidemiological study on children. This method also does not provide detailed information about the various levels of intensity of physical activity(120).

2.5.2.1.2 Separate accelerometers and heart rate monitors

Accelerometers and heart rate monitors have various advantages and disadvantages. When combined into one device (as in the Actiheart monitor) this negates many of the disadvantages of each(121). Accelerometery is a thoroughly validated method of objectively measuring physical activity. DLW has been used to validate the different types of accelerometers(122). Different models of accelerometer have been made which can measure acceleration in one (uniaxial), two (biaxial) or three (triaxial) directions. The accelerometer within the Actiheart is uniaxial meaning that it only measures in the vertical plane. However, research has shown that uniaxial monitors do not differ in their ability to measure physical activity compared with triaxial(123-125). The main limitation of accelerometery is its inability to measure activities such as cycling and upper body strengthening exercises(126). In addition, accelerometers are unable to detect when the intensity of an activity, such as walking, is increased by an additional load or steeper gradient(127,128). A further problematic area is the identification of non-wear time. The inclusion of non-wear time would lead to a falsely exaggerated measure of sedentary time.

In comparison, heart rate monitors produce an easy to interpret output. Energy expenditure can be derived on the basis that throughout steady state activity, there is a linear relationship between heart rate and energy expenditure(129). Heart rate monitoring, when combined with accelerometery, can be used to improve the validity of results by capturing activities such as cycling due to the increase in heart rate. An implausible heart rate output is also a more reliable method of detecting non-wear time compared to low acceleration values from an accelerometer. In contrast, accelerometers can be used to negate some of the limitations of heart rate monitoring. Firstly, pain and stress are known factors that increase heart rate(130,131). Accelerometers are able to identify that this change in heart rate is not activity induced. In addition, during exercise there is a lag-time between the commencement of exercise and the increase in heart rate. Similarly, a further lag-time is seen at the end of activity before a drop in heart rate occurs, which is correlated with an individual's fitness level(119,132). Accelerometery is able to establish these activity start and end points accurately whereas heart rate monitoring would be unable to do so.

2.5.2.1.3 Pedometry

Pedometers are motion detectors that are usually placed around the waist or hips in order to detect the acceleration that occurs during the gait cycle(133). Their primary output is the number of steps taken by a participant per day. They are a relatively cheap method of measuring physical activity objectively, and have been shown to be valid. Comparison of pedometers with accelerometers has shown a median correlation of r=0.86(134). However, there is a lack of evidence regarding the validity of pedometers in children under the age of 6 years(135).

Pedometers are not without their limitations. Similarly to DLW, pedometers are unable to give information about the level of intensity of physical activity – they can only measure walking(136). This also means that they are unable to record other types of physical activity such as swimming and cycling(137,138). Furthermore, research has shown that if an individual walks very slowly (<2 mph), the number of steps given by the pedometer is often inaccurate(139). A further limitation, which would be particularly problematic in a study including children as the participants, is that pedometers can often be tampered with and shaken in order to increase the number of steps recorded(138), producing invalid data. Finally, there is currently no reliable method of converting the number of steps per day into PAEE(102,135,135,140).

2.5.2.2 Subjective methods

2.5.2.2.1 Questionnaires

Questionnaires are the easiest and quickest method of collecting physical activity information from a large population. Unlike objective methods, they also have the ability to collect information about the type of physical activity carried out by an individual. There are many paediatric physical activity questionnaires available for use by researchers which have been validated in some format(141,142). The main aim of most of these questionnaires is to categorise the study population based on their physical activity levels. Sometimes the various types of physical activity are assigned METs in order to attempt to calculate PAEE using a compendia of physical activity(143,144). However, the ability of questionnaires to do this accurately is limited(145,146). For young children, parents are often required to complete the questionnaire and are unlikely to know about all of their child’s activity, such as that which occurs during the school day. Young children’s activity is also relatively unstructured and therefore difficult to recall and report on in a questionnaire. Questionnaires are also open to social desirability(147) and recall bias(107,107,148), and generally have poor overall reliability(145,149-151).

2.5.2.2.2 Time diaries

To complete a time diary, participants are asked to record any physical activity as it happens at regular intervals (e.g. every 15 minutes) throughout the day. This prospective method of recording reduces the risk of recall bias. Often, participants are given a coded list of different activities and are asked to fill in the diary according to which activity has taken place. In this way, METs can be assigned to the various activities(152). However, conversion to PAEE is still difficult and relies on the researcher's interpretation of the diary(107,119,153). Time diaries suffer from many of the same problems as questionnaires. They are subject to social desirability bias and are also considered too complex for young children to complete themselves, and parental reports have been shown to have low validity(154).

2.5.2.2.3 Direct observation

During direct observation, a researcher observes the physical activity of children during a period of time in a controlled setting, such as over a school break time. Programmes have been developed allowing researchers to input data directly into a laptop with the use of a coding form(155,156). This has led to a high inter-observer reliability of between 84% and 99%(157). Rich contextual information can be obtained. However, information about the level of intensity of the activity is open to researcher bias(143,144). Participants may also alter their usual behaviour due to the fact that they are aware of being watched(158). For a large-scale study, this method is likely to be too resource-intensive to be feasible.

2.5.2.5 Summary

In summary, Actiheart (a combined accelerometer and heart rate monitor) was the method of choice for the WAVES study. This method has been shown to produce valid estimates of PAEE in children(159). It does not suffer from the multiple forms of bias that subjective methods are flawed by and is able to measure a range of different levels of intensity of activity. Finally, the Actiheart is feasible for use in a large-scale study.

2.6 Measurement of sedentary behaviour

A combination of objective and subjective methods were used to measure the sedentary behaviour of each child. This was done to obtain an objective measure of total time spent being sedentary, in addition to contextual information on how long each child spent participating in a range of sedentary activities.

The sedentary behaviour variables that have been used for analyses outlined in this thesis are as follows:

- Total sedentary time (hours/day)
- TV viewing time (hours/day)
- Computer and video-gaming time (hours/day)
- Time spent reading and on homework (hours/day)
- Time spent doing craft (hours/day)

2.6.1 Objective measure of sedentary behaviour

The sedentary behaviour variable that was collected using an objective method, was the total sedentary time. These data were obtained with the use of the Actiheart monitor, the details of which have been previously outlined in Section 2.5.1. The cut-off for vertical acceleration which was used to determine the time spent being sedentary was ≤0.075 m/s^2(102). This time was converted into hours per day. The Actiheart monitor is unable to differentiate between the time spent being sedentary whilst awake and that which occurs when an individual is asleep. It is known that a short sleep duration in children is associated with an increased risk of overweight/obesity(160), and it is therefore important to account for sleep duration in some way. To do this, an additional variable was created by subtracting parent-reported sleep duration from the objectively measured total sedentary time. This new variable was used to conduct sensitivity analyses in order to examine whether this new variable behaved in a similar manner during analyses compared with the total sedentary time variable that included sleep duration.

2.6.2 Subjective measures of sedentary behaviour

As part of the WAVES study, parents were asked to complete a questionnaire at each data collection time-point. This can be seen in Appendix 1. The parental questionnaire asked parents how long their child spends on a typical week day and a typical weekend day watching TV, playing video-games or using the computer, doing craft and doing homework/reading. The average time spent per day over a typical week was calculated by: ((5 x duration on week days) + (2 x duration on weekend days))/7.

Alternative methods of collecting data about the type of sedentary behaviour that individuals undertake include direct observation and ambulatory diary assessment. Direct observation by either video-recording or researcher observation is considered to be the gold standard for this type of data collection. However, this method may cause behaviour alteration and is resource intensive. In ambulatory diary assessment, individuals record their current activity at regular intervals(161). This method has been tested in adults and adolescents, but is unlikely to be feasible in young children(161-163).

2.7 Measurement of adiposity

A range of anthropometric measurements were taken from the children participating in the WAVES study at each of the data collection time-points. All data were collected during the school day by trained researchers who followed standardised protocols. Methods were chosen for their feasibility to gather information on a large-scale within school environments. Due to the participants being young children, it was also important to use non-invasive techniques that were quick to carry out. The primary aim of the WAVES study was to examine the effectiveness of the intervention to reduce levels of overweight/obesity. Accurate estimates of body composition were therefore required. This section outlines the various measures of adiposity that were collected as part of the WAVES study and that have been used in the analyses presented in this thesis.

2.7.1 BMI z-score

Weight and height measurements were taken from children when they were wearing light clothing as per the standardised study protocols (Appendix 2 and Appendix 3). Weight was measured to the nearest 0.1 Kg using Tanita SC-331S body composition analyzer (Tanita, Tokyo, Japan). Height was measured twice, to the nearest 0.1 cm using a Leicester height measure. BMI was calculated (weight in Kg divided by the square of the height in metres) as it is the most regularly used method of estimating adiposity in both adults and children(164,165). BMI was converted into BMI z-scores using the British 1990 growth reference data (UK90)(166) to take account of developmental patterns as children grow and the variation between boys and girls. BMI z-scores represent the number of units of the standard deviation (SD) a child's BMI is above or below the mean BMI value for a child of that age and sex(166). Children were categorised as overweight or obese using the UK90's 85th and 95th centiles as cut-offs. Previous research in children has shown that a BMI above the 95th centile is associated with adverse levels of cardiovascular health markers(79).

BMI z-score is an important measure of weight status as it is very commonly used and therefore allows comparison with other studies, and it is used in public health policy reports. The main disadvantage of BMI as a measure of estimating adiposity, is its inability to differentiate between fat mass and fat free mass(167,168). This means that individuals with a relatively high muscle mass, can be incorrectly labelled as overweight/obese(79,80).

2.7.2 Waist circumference z-score

Waist circumference was measured twice at each data collection time-point, with a third measurement if there was a discrepancy of more than 0.4 cm between the two, using a standard, non-stretch tape measure. Measurements were taken to the nearest 0.1 cm and an average of the two closest readings was calculated and used. Researchers were trained to take the waist measurements at the point half-way between the anterior superior iliac spine and the bottom rib. In a similar fashion to BMI, waist circumference measurements were converted into z-scores using UK reference data(169). This was done because, like BMI, waist circumference in children is influenced by their age, gender and level of maturation(169).

Waist circumference has been included in order to provide detail about the distribution of body fat which BMI alone is unable to provide. Waist circumference measurements correlate with the amount of central adiposity, which has been shown to be independently associated with a range of cardiovascular health markers in both children and adults(4,170-174). Specifically in children, a high level of central fat has been linked with adverse levels of lipoproteins and lipids, and a high blood pressure(40,175,176). Magnetic Resonance Imaging (MRI) and Computed Tomography (CT) validation studies have shown that this increased cardiovascular risk is caused by visceral adiposity(177,178). Visceral adiposity refers to the fat distributed around the visceral organs and within the abdominal cavity(179).

2.7.3 Skinfold thickness

Skinfold thickness measurements were taken from children using Holtain skin calipers, at four different sites: triceps; biceps; subscapular and suprailiac. In a similar fashion to waist circumference, measurements were taken twice and an average calculated. A third measurement was only taken if the two values differed by more than 0.4 mm. In order to produce a single variable that represents total adiposity, the values for skinfold thickness at each of the four body sites were summed. This summed value is the skinfold thickness variable that has been used in analyses.

Skinfold thickness, like waist circumference z-score, also provides information about the distribution of body fat. It can be used to give an estimation of the amount of subcutaneous fat an individual has(180,181).

The main disadvantage of skinfold thickness as an adiposity measure is that it has a low inter-researcher reliability(182). This was minimised by the use of researcher training, repeat measurements and standardised protocols.

2.7.4 Body fat percentage

Body fat percentage (BF%) was the fourth and final measure of adiposity used in the analyses. Tanita bioimpedance scales (Tanita SC-331S, Japan) were used in the WAVES study to measure leg-to-leg bioimpedance. Children wore light clothing and had bare feet. Height was entered into the machine before measurements were taken. Bioelectrical impedance measures the obstruction by body compartments to an electrical current. It is therefore able to differentiate between fat mass and lean mass due to the fact that lean mass has a higher water content compared to fat mass and so has a higher electrical conductivity (less obstruction)(182,183).

The scales produce the following measurements: fat mass; lean mass; bone mineral content; total body mass and BF%. These were produced using the manufacturer's regression equations which use the child's height and impedance to calculate total body water(184). It is known that approximately 73% of lean mass consists of water and so lean mass can be calculated once a value for total body water is obtained(185,186). Simple subtraction of lean mass from body weight can give a value for fat mass(186). BF% can then be calculated by: (fat mass / body weight) x 100.

BF% measurements obtained from leg-to-leg bioimpedance have been shown to have relatively strong agreement with those produced from dual energy X-ray absorptiometry (DXA) scanning, which is a standard method to estimate BF% with proven accuracy(187-

190). However, it is possible that bioimpedance produces values of BF% that are a little higher than those from DXA scanning(189). Bioimpedance also provides a value for fat mass, which is important to be able to consider alone due to its associations with adverse health outcomes(191). The main disadvantage of bioimpedance is that the regression equations used by the analyser are based on reference populations which do not necessarily have the same characteristics as the children in the WAVES study(183). Furthermore, the estimation of total body water requires lean mass tissue to be hydrated(186). States of dehydration can therefore provide inaccurate values of BF%(192).

2.7.5 Summary of methods to measure adiposity

Using a range of adiposity measures increases the validity of any conclusions drawn from the analyses. This is because previous literature has identified that the relationship between physical activity and weight can differ depending on which measure of adiposity is used as the outcome variable(67). Furthermore, the WAVES study has an ethnically diverse study sample. It is known that the values obtained by the various methods of measuring adiposity can be influenced by ethnicity(193-195). For example, previous investigations have shown that South Asian children aged 9-10 years have higher fat mass and skinfold thicknesses, but lower BMIs, when compared with White British children(193). In contrast, when Black African children are compared to White British children they have been shown to have lower skinfold thicknesses and BF%, but higher BMIs(193,194).

There are more sophisticated methods available to measure body composition. These include DXA, MRI, CT and isotope solutions. DXA, MRI and CT are all imaging techniques.

Isotope dilution allows total body water to be estimated through the ingestion of a known quantity of non-radioactive isotope alongside water. The concentration of the isotope in blood, urine or saliva samples after equilibration can then be used to deduce total body water. Using the fact that 73% of fat free mass consists of water; fat free mass, fat mass and BF% can then be obtained(185,186). The above methods can give accurate values for BF% and total adipose tissue(186,196-198). However, the techniques are too expensive and impractical to use within large population studies of healthy children.

2.8 Measurement of additional variables

2.8.1 Ethnicity

Each child's ethnic group was obtained from the parental questionnaire. A list of 18 ethnic groups, which was taken from the 2001 census(199), was given to parents and they were asked to select the most appropriate. These 18 ethnic groups were then collapsed into 4 categories for the purpose of analysis. These were: White British, South Asian (Indian, Pakistani and Bangladeshi), African Caribbean (Black African and Black Caribbean) and other ethnic groups (included mixed ethnicity). The pupils' schools were also asked to provide the ethnicity of pupils, and this data was used if the parental questionnaire item was missing.

2.8.2 Socioeconomic status

Each child's postcode was obtained from both the school and the parental questionnaire, and this was used to derive a proxy for socioeconomic status. Postcode enabled identification of the 2010 Lower Super Output Area (LSOA) that each participant lived in. Each LSOA is assigned an Index of Multiple Deprivation (IMD) score, which is a measure of the area's deprivation(200). This is determined by a range of factors which cover crime, access to services, income, employment, education, health and living environment. Five socioeconomic groups were then obtained by dividing the IMD 2010 scores into quintiles based on cut-offs obtained from the national ranking of IMD scores for all LSOAs.

2.9 Statistical analysis

All data were analysed using SPSS version 22 (SPSS, Inc., Chicago, IL, USA).

2.9.1 Change in and tracking of physical activity and sedentary behaviour (presented in Chapter 3)

All values of physical activity and sedentary behaviour were assessed for normality. Differences in physical activity and sedentary behaviour values between boys and girls at each measurement time-point were assessed with independent samples t-tests. Differences in physical activity and sedentary behaviour values between the three data collection time-points (baseline, follow-up 1 and follow-up 2) for the overall sample and for boys and girls separately were assessed using repeated measures analysis of variance (ANOVA).

The tracking of physical activity and sedentary behaviour was assessed using three statistical methods:

1. The correlations between baseline and follow-up 2 for each measure of physical activity and sedentary behaviour were assessed using Spearman rank-order correlation. This was conducted for the overall sample and by gender.
2. Each physical activity and sedentary behaviour variable was split into quartiles. Logistic regression analysis was used to determine the odds of a child who, at

baseline, was in the highest quartile, staying in that same quartile at follow-up 2 relative to children in the lowest three quartiles at baseline. This method was repeated to then determine the odds of a child who, at baseline, was in the lowest quartile, staying in that quartile. The models were adjusted for age at baseline, ethnicity, socioeconomic status, gender and arm of WAVES study. Again, this was conducted on the overall sample and then by gender.

3. The change in each physical activity and sedentary behaviour variable between follow-up 1 and baseline, and follow-up 2 and follow-up 1 was calculated. The change in physical activity and sedentary behaviour between each point was then categorised depending on whether there was an increase, a negligible change or a decrease in the measure of activity. Negligible change boundaries were determined through examination of the SD and normal distribution of each change in physical activity/sedentary behaviour variable between time-points. Negligible changes were defined as follows: between -20 and +20 minutes/day for MVPA, between -15 kJ/Kg/day and +15 kJ/Kg/day for PAEE and between -45 minutes/day and +45 minutes/day for total sedentary time. The categories between each time-point (i.e. baseline to follow-up 1 and follow-up 1 to follow-up 2) were then compared in order to create 9 overall categories:
    a) increase, increase;
    b) increase, negligible change;
    c) increase, decrease;
    d) negligible change, increase;
    e) negligible change, negligible change;

f) negligible change, decrease;

g) decrease, increase;

h) decrease, negligible change;

i) decrease, decrease.

Simple percentages were used to describe the proportion of children within each of these categories.

The mean change in activity per year was calculated for boys and girls for each variable. Unadjusted values were calculated by a simple equation: Difference in the activity variable between baseline and follow-up 2 / Difference in age between baseline and follow-up 2. Adjusted mean change values (estimated marginal means) were then obtained using analysis of covariance (ANCOVA) in which socioeconomic status, ethnicity and the arm of the WAVES study a participant was in, were added as covariates.

2.9.2 The longitudinal association between physical activity and sedentary behaviour, and adiposity (presented in Chapter 4)

Each measure of adiposity was assessed for normality. Independent samples t-tests were used to assess for significant differences in the measures of adiposity between boys and girls at baseline, follow-up 1 and follow-up 2. Repeated measures ANOVA was used to investigate if there were significant differences between the measures of adiposity at baseline, follow-up 1 and follow- 2 for the overall sample and for boys and girls separately.

Multilevel linear regression models were used to examine associations between the change in the measures of physical activity and sedentary behaviour between baseline and follow-up 2, and the various measures of follow-up 2 adiposity. Each predictor variable was modelled separately. The predictor variables were the changes in MVPA, PAEE, total sedentary time, time spent watching TV, time spent carrying out other screen activities (computer and video-game use) and time spent carrying out other sedentary behaviours (reading, homework and craft). The physical activity variables (change in MVPA and change in PAEE) were calculated by subtracting the follow-up 2 value from the baseline value. This was done so that the effect on adiposity of a decrease in these physical activity measures could be examined (i.e. a higher value indicates a greater decrease in physical activity from baseline to follow-up 2). For the sedentary behaviour variables, change was calculated as: (follow-up 2 value – baseline value) in order for the effect on adiposity of an increase in sedentary time to be determined (i.e. a higher value indicates a greater increase in sedentary time from baseline to follow-up 2).

Outcome variables were all based on measurements at follow-up 2: BMI z-score, waist circumference z-score, BF% and sum of skinfolds. To account for the clustered nature of the data, the school that each child attended was added as a random effect. For each measure of physical activity and sedentary behaviour, three models were constructed:

1. Model 1: Adjusted for the relevant baseline measure of adiposity and baseline measure of physical activity or sedentary behaviour.
2. Model 2: Socio-demographic baseline variables of age, gender, ethnicity, socioeconomic status and the arm of the WAVES study that the child was in were added into the model as covariates, in addition to the relevant baseline measures of adiposity and physical activity/sedentary behaviour.

3. Model 3: In addition to the adjustments made in Model 2, the change in total sedentary time was entered into models examining the association between the measures of physical activity and adiposity. The models examining the association between the measures of sedentary behaviour and adiposity were further adjusted for the change in PAEE.

All of the above analyses were then repeated for boys and girls separately. Gender was not added as a covariate in these analyses.

2.9.3 Sensitivity analyses

In order to account for sleep duration, all analyses using the total sedentary time variable were repeated using the variable where parent-reported sleep duration had been subtracted from the total sedentary time.

CHAPTER 3: CHANGE AND TRACKING OF PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR THROUGHOUT THE MIDDLE CHILDHOOD YEARS

3.1 Aims and objectives

This chapter presents the results from the analyses conducted, relating to the changes in and tracking of physical activity and sedentary behaviours, from 5-6 years to 8-9 years. The primary aims for these analyses were to investigate whether levels of physical activity and sedentary behaviour track throughout the middle childhood years, and to determine how the levels of physical activity and sedentary behaviour change throughout this period of childhood.

The specific objectives were as follows:

- Describe the levels of physical activity and sedentary behaviour at baseline and each follow-up time-point in the overall sample and by gender.
- Explore the degree of tracking between baseline and follow-up values of physical activity and sedentary behaviour.
- Calculate the rate of change in physical activity and sedentary behaviour per year of age increase in children between the ages of 5-6 years and 8-9 years, whilst adjusting for appropriate covariates.

Based on previous literature on children, it is hypothesised that the measures of physical activity will decrease from baseline to follow-up(19,48,52,57,59), and sedentary behaviour levels will increase(19,48,52,53,57). It is also expected that sedentary behaviours, especially TV viewing time, will track at a stronger level compared with physical activity measures(48,61-63).

3.2 Participant characteristics

Parental consent for participation in the WAVES study was obtained from 1467 children (60% of eligible children). 502 children (34% of total sample) provided valid Actiheart data for all 3 data collection time-points. African Caribbean children were less likely to provide valid Actiheart data than children from other ethnic groups (p=0.001). However, there were no differences between those who did and did not provided data in terms of weight status, socioeconomic status and gender. At baseline, the mean time that children wore the Actiheart monitor for was 102 hours, this time slightly reduced as the study progressed to 100 hours and 97 hours for follow-up 1 and follow-up 2 respectively. The parents of 549 children (37% of total sample) completed the parental questionnaire at all 3 data collection points. The number of children with a completed parental questionnaire dropped as the study progressed. At baseline, 64% of parents of participating children responded compared with 54% of parents at follow-up 2. The children who had completed questionnaires were more likely to be White British (p=<0.001) and in the least deprived IMD quintile (p<0.001).

The baseline socio-demographic and anthropometric characteristics of the overall sample and by gender can be seen in Table 3.1. At baseline, children were on average 6.29 ± 0.31 years old. 45% of children were White British whilst 31% were South Asian. The majority of children (55%) were from the most deprived IMD quintile. 21% of the children were either overweight or obese at baseline.

Table 3.1: Baseline socio-demographic and anthropometric characteristics of the entire sample and by gender.			
	Boys n=749 (51.1%)	**Girls** n=718 (48.9%)	**Total** n=1467
Age, mean (SD), years n=1397	6.30 (0.31)	6.27 (0.31)	6.29 (0.31)
Ethnicity, n (%), n=1451			
White British	329 (44.3)	329 (46.4)	658 (45.3)
Asian	225 (30.3)	218 (30.7)	443 (30.5)
African Caribbean	61 (8.2)	54 (7.6)	115 (7.9)
Other	127 (17.1)	108 (15.2)	235 (16.2)
Socioeconomic status (IMD Quintile), n (%), n=1439			
1 = most deprived	416 (56.5)	374 (53.2)	790 (54.9)
2	144 (19.6)	130 (18.5)	274 (19.0)
3	79 (10.7)	67 (9.5)	146 (10.1)
4	52 (7.1)	67 (9.5)	119 (8.3)
5 = least deprived	45 (6.1)	65 (9.2)	110 (7.6)
BMI, mean (SD), n=1395	16.19 (2.44)	16.05 (2.24)	16.12 (2.35)
BMI z-score, mean (SD), n=1392	+0.24 (1.31)	+0.14 (1.12)	+0.19 (1.22)
Weight status category[a], n (%), n=1392			
Underweight	28 (3.9)	12 (1.8)	40 (2.9)
Normal	524 (72.8)	533 (79.3)	1057 (75.9)
Overweight	67 (9.3)	57 (8.5)	124 (8.9)
Obese	101 (14.0)	70 (10.4)	171 (12.3)

[a]Weight category from calculation of BMI z-score using UK 1990 reference centile curves and cut-offs used for population monitoring.

3.3 Descriptive statistics

Table 3.2 displays the mean values (alongside the standard deviation) for each measure of physical activity and sedentary behaviour at each data collection point for the overall sample and by gender.

3.3.1 Physical activity

From baseline to follow-up 2, there was an overall statistically significant decrease in both the number of minutes spent in MVPA and total physical activity (measured as

PAEE). At baseline, the mean number of minutes spent in MVPA per day was 71.8 ± 49.3 and 48% of the overall sample were meeting the UK government's recommendations of ≥60 minutes of MVPA per day. By follow-up 2, both of these values had dropped substantially to give a mean number of minutes spent in MVPA per day of 53.0 ± 35.9 and the proportion of children meeting recommendations was just 27%.

Figure 3.1 shows the adjusted mean number of minutes spent in MVPA per day separately for boys and girls, at each data collection point. For both genders there is a small yet significant increase in the mean time spent in MVPA from baseline to follow-up 1 (for boys an increase of 10.0 minutes/day and for girls an increase of 5.6 minutes/day). This is then followed by a dramatic decrease in the mean time spent in MVPA from follow-up 1 to follow-up 2 (a decrease of 29.2 minutes/day for boys and 26.0 minutes/day for girls). The changes in PAEE between the three time-points did not show this pattern, and instead showed a constant decline from 95.2 kJ/Kg/day at baseline to 91.5 kJ/Kg/day at follow-up 1, and then to 79.1 kJ/Kg/day at follow-up 2.

At all time-points, boys were more physically active compared with girls. At each data collection point, approximately 15% more boys than girls met the UK MVPA recommendations.

3.3.2 Sedentary behaviour

Total sedentary time and the time spent in the various sedentary behaviours (with the exception of craft time) increased from 5-6 years to 8-9 years. Total sedentary time, computer and video-game use and homework/reading time all significantly increased, whilst the time spent doing craft significantly decreased. Total sedentary time (including sleep) increased from 14.5 ± 1.8 hours/day at baseline to 15.8 ± 1.9 hours/day at follow-up 2. The TV viewing time of the overall sample also showed an increase, however this was non-significant.

For the overall sample there was a small but significant decrease of 27 minutes/day in total sedentary time from baseline to follow-up 1. This was followed by a dramatic and significant increase between follow-up 1 and 2 of 104 minutes/day. This pattern of a decrease, followed by a large increase was seen for both boys and girls, as can be seen from the adjusted mean values shown in Figure 3.2.

Overall, there were less marked differences in the measures of sedentary behaviour between boys and girls compared with the measures of physical activity. For example, despite the fact that at baseline girls had significantly higher total sedentary time compared with boys, there were no significant differences in the total sedentary time of boys and girls at both follow-up 1 and follow-up 2. Furthermore, no significant differences were seen between the genders for TV viewing and homework/reading time at all three data-collection points. In contrast, boys consistently spent more time per day on the computer and playing video-games (16 minutes more at baseline, 20 minutes at follow-up 2) whilst girls spent more time per day doing craft (also 16 minutes more at baseline, 19 minutes at follow-up 2). There was also a significant increase in the TV viewing time across the three time-points for girls only. At baseline, girls watched less TV than boys (2.2 ± 1.2 hours/day for girls versus 2.3 ± 1.1 hours/day for boys). However, whilst TV viewing time stayed relatively constant for boys over the study period, it increased for girls from baseline to follow-up 2, to give a value of 2.5 ± 1.3 hours/day at follow-up 2 versus 2.3 ± 1.3 hours/day for boys.

Table 3.2: Mean value and standard deviation for activity-related characteristics of the entire sample and by gender.

	Baseline (5-6 years)			Follow-Up 1 (7-8 years)			Follow-Up 2 (8-9 years)		
	Boys n=544[c] (51.7%)	**Girls** n=508[c] (48.3%)	**Total** n=1052[c]	**Boys** n=439 (50.6%)	**Girls** n=429 (49.4%)	**Total** n=868	**Boys** n=363 (52.6%)	**Girls** n=327 (47.4%)	**Total** n=690
MVPA, mins/day	78.12 (51.29)	65.11 (46.30)	71.81 (49.34)	87.14 (58.02)	71.34 (54.37)	79.28 (56.75)	59.43 (38.07)	45.85 (31.99)	52.99 (35.94)
PAEE, kJ/Kg/day	101.75 (24.51)	88.13 (20.92)	95.18 (23.83)	97.59 (24.83)	85.20 (22.83)	91.47 (24.64)	85.03 (23.54)	72.45 (18.87)	79.07 (22.34)
Total sedentary time, hrs/day	14.39 (1.89)	14.62 (1.78)	14.50 (1.83)	13.96 (2.22)[a]	14.15 (2.10)	14.05 (2.16)	15.84 (2.00)[a]	15.72 (1.79)	15.78 (1.90)
TV viewing time, hrs/day[c]	2.32 (1.14)[a, b]	2.18 (1.18)	2.25 (1.16)[b]	2.38 (1.20)[a]	2.28 (1.20)	2.33 (1.20)	2.31 (1.26)[a]	2.50 (1.31)	2.41 (1.29)
Computer and video-game use, hrs/day[c]	1.17 (0.87)	0.91 (0.83)	1.05 (0.86)	1.46 (1.12)	1.08 (0.99)	1.27 (1.07)	1.70 (1.15)	1.37 (1.03)	1.53 (1.10)
Homework and reading, hrs/day[c]	0.88 (0.60)[a]	0.92 (0.65)	0.90 (0.62)	0.97 (0.73)[a]	1.00 (0.66)	0.98 (0.70)	1.08 (0.81)[a]	1.11 (0.72)	1.09 (0.76)
Craft time, hrs/day[c]	0.90 (0.72)	1.16 (0.75)	1.04 (0.75)	0.81 (0.72)	1.05 (0.76)	0.93 (0.75)	0.70 (0.64)	1.02 (0.70)	0.87 (0.69)
Percentage meeting UK MVPA recommendations, n (%)[d]	299 (55.4)	205 (40.4)	504 (48.1)	257 (59.1)	184 (42.7)	425 (50.9)	126 (34.2)	64 (19.3)	190 (27.1)

Independent samples t-tests were used to test for mean differences between boys and girls at baseline and each follow-up time-point. Repeated measures ANOVA was used to test for significant differences for the overall sample, boys and girls across the three data collection points. Significance was taken to be $p<0.05$. All comparisons were significant except as indicated below:

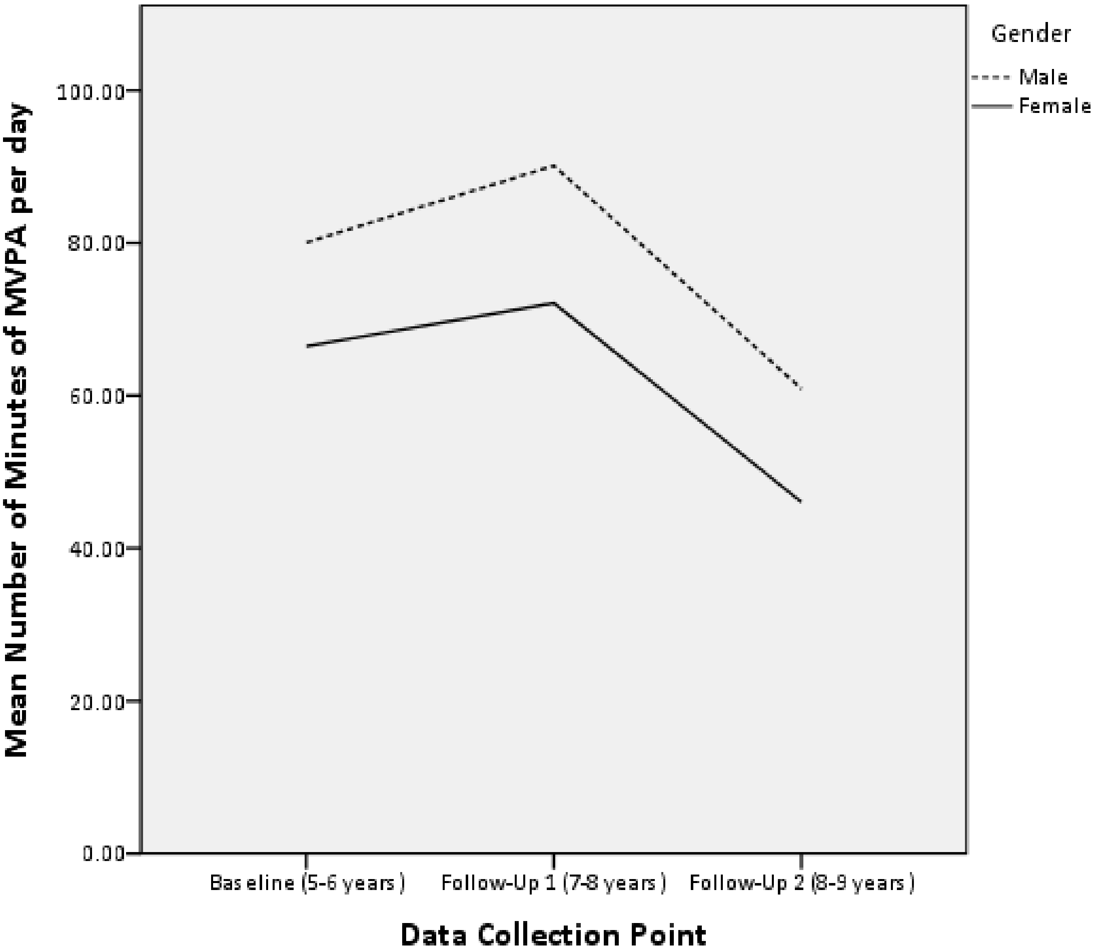
[a]Not significant between boys and girls at baseline, follow-up 1 or follow-up 2

[b]No significant difference between time-points for total sample, boys or girls.

[c]For the individual sedentary behaviours, n for total sample = 939 (Baseline), 842 (Follow-Up 1) and 785 (Follow-Up 2). N for boys = 477 (Baseline), 426 (Follow-up 1), 382 (Follow-up 2). N for girls = 462 (Baseline), 416 (Follow-Up 1), 403 (Follow-Up 2).

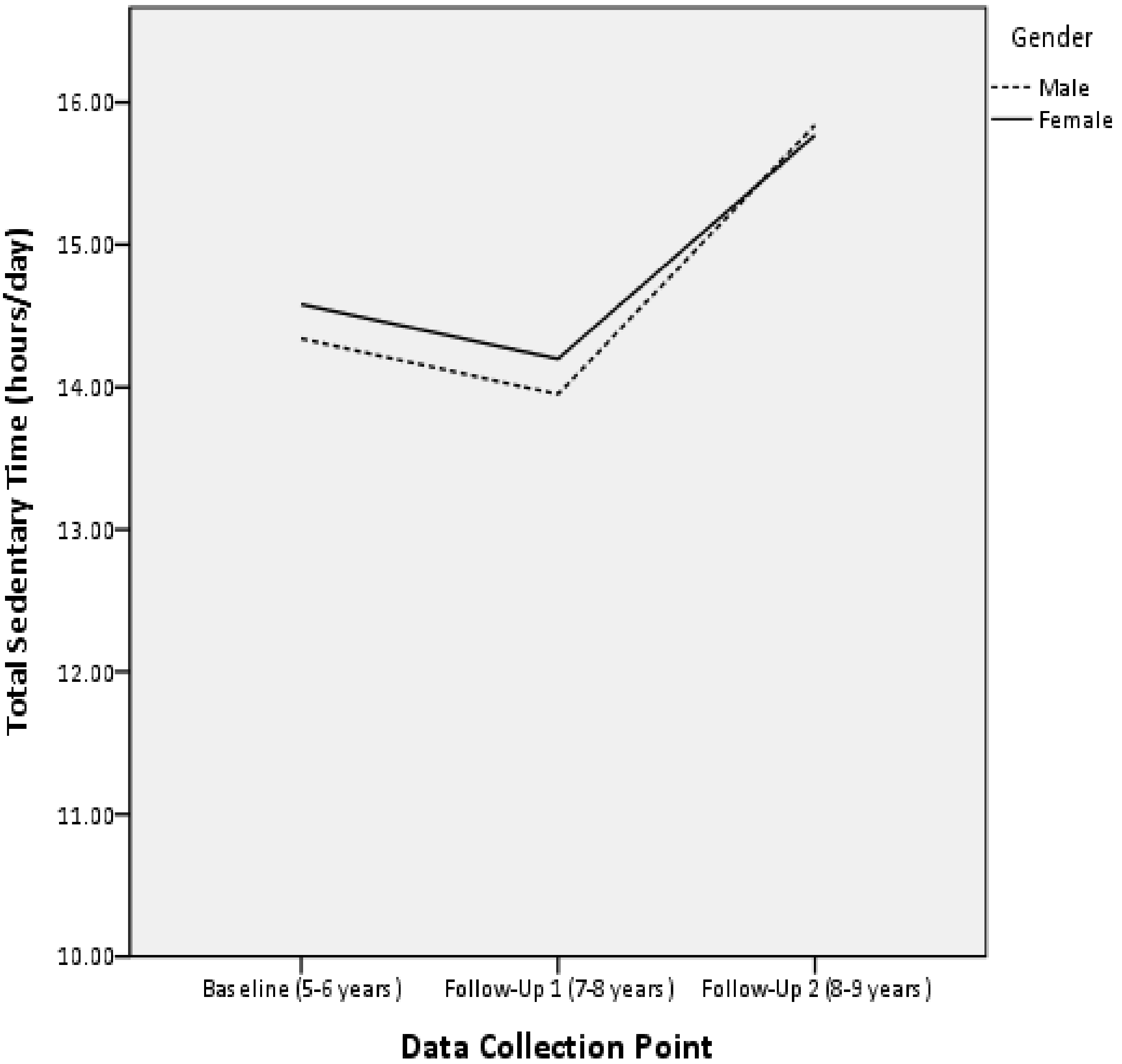
[d]Comparisons were not performed for differences between time-points for the % of children meeting UK recommendations. Pearson's χ^2-test was used to test for significant differences between boys and girls in the proportion of children meeting UK MVPA recommendations.

Figure 3.1: Mean number of minutes of MVPA carried out per day for boys and girls.



Mean was adjusted for: Arm of WAVES study, socioeconomic status and ethnicity.

Figure 3.2: Mean total sedentary time per day for boys and girls.



Mean was adjusted for: Arm of WAVES study, socioeconomic status and ethnicity.

3.4 Tracking of physical activity and sedentary behaviour

Table 3.3 displays the Spearman-rank correlation coefficients representing the stability of the physical activity and sedentary behaviour measures from baseline to follow-up 2. All coefficients were statistically significant at the $p<0.01$ level. PAEE and the separate sedentary behaviours all tracked at moderately strong levels, and showed the strongest tracking when compared with the other measures. For both boys and girls, PAEE was the most stable behaviour (r=0.46 for boys and 0.45 for girls). Despite the fact that the individual sedentary behaviours tracked at moderately strong levels, the overall measure of total sedentary time only tracked weakly (r=0.20). Generally, these individual sedentary behaviours tracked at stronger levels in boys compared with girls, especially the time spent on the computer/playing video-games and the time spent on homework. The results presented in Table 3.3 suggest that between 5-6 years and 8-9 years, total physical activity remains a relatively stable behaviour (r=0.50), whereas a child's MVPA at 5-6 years only weakly correlates with their level at 8-9 years (r=0.29).

Table 3.3 Spearman-rank correlation coefficients between the baseline and follow-up 2 values of each activity-related variable.			
	Male	**Female**	**Overall Sample**
MVPA, mins/day	**0.24**	**0.27**	**0.29**
PAEE, kJ/Kg/day	**0.46**	**0.45**	**0.50**
Total sedentary time, hrs/day	**0.19**	**0.23**	**0.20**
TV viewing time, hrs/day	**0.38**	**0.40**	**0.38**
Computer and video-game use, hrs/day	**0.39**	**0.27**	**0.35**
Homework and reading, hrs/day	**0.36**	**0.22**	**0.29**
Craft time, hrs/day	**0.41**	**0.30**	**0.39**
Bold font represents statistical significance at the p<0.01 level.			

Table 3.4 shows the likelihood of a child who is in the highest quartile for each of the activity measures at baseline (i.e. the most active and the most sedentary), staying in the highest quartile at follow-up 2, compared to children in the lowest three quartiles at baseline. Again, this represents the stability of each of these activities and behaviours over time. For the percentage of children meeting UK MVPA recommendations, quartiles were not used and instead the odds ratios refer to the likelihood of a child who was carrying out the recommended amount of MVPA at baseline maintaining this at follow-up 2, relative to children who did not meet recommendations at baseline. Table 3.5 also presents odds ratios, however in this table the odds displayed represent the likelihood of a child who is in the lowest quartile for each measure at baseline (i.e. the least active and the least sedentary quartiles), staying in the lowest quartile at follow-up 2, compared to children in the highest three quartiles at baseline. The results in Table 3.4 add further evidence to suggest that the sedentary behaviours track at a stronger level in boys compared to girls, most notably computer and video-game use (OR=8.04, 95%CI=3.72,

17.38 versus 2.70, 95%CI=1.10, 6.61). However, Table 3.5 shows that the likelihood for a girl maintaining a low level of TV viewing is much higher compared to a boy (OR=4.41, 95%CI=2.33, 8.33 versus 1.33, 95%CI=0.69, 2.58).

The results displayed in Tables 3.4 and 3.5 show additional evidence to suggest that PAEE is more stable over time compared with MVPA. Children who carried out the most total physical activity aged 5-6 years, were 3.31 times as likely to continue doing so at 8-9 years. Those who carried out the least total physical activity aged 5-6 years, were 5.91 as likely to retain this low total physical activity level. In contrast, the adjusted odds ratios for maintaining the highest and the lowest levels of MVPA were just 1.57 and 1.64 respectively. Children who met the UK's MVPA recommendations at baseline were 2.13 times as likely to carry on doing so at follow-up 2, compared with those who did not meet the recommendations at baseline. The socio-demographic and anthropometric characteristics of the children who continued to meet the government's MVPA recommendations compared with those who met the guidelines at baseline, but who had then stopped meeting them by follow-up 2 were examined, and these results can be seen in Table 3.6. It was found that boys were significantly more likely to continue to carry out ≥60 minutes of MVPA compared with girls ($p=<0.01$), and White British and African Caribbean children were more likely compared with other ethnic groups ($p=0.03$). No differences were found in terms of weight status and socioeconomic group.

Table 3.4 Likelihood of maintaining levels of activity from baseline to follow-up (i.e. likelihood of those in the highest activity and sedentary quartile at baseline staying in the same quartile at follow-up 2, compared to children in the lowest three quartiles at baseline).

	Boys **Odds Ratio (95% CI)**	**Girls** **Odds Ratio (95% CI)**	**Overall sample** **Odds Ratio (95% CI)**
MVPA, mins/day	1.28 (0.70, 2.34)[a]	2.25 (1.19, 4.25)	1.57 (1.02, 2.42)
PAEE, KJ/Kg/day	2.82 (1.58, 5.04)	2.34 (1.24, 4.41)	3.31 (2.13, 5.12)
Percentage meeting UK MVPA recommendations (%)[b]	2.36 (1.41, 3.94)	1.88 (0.99, 3.59)[a]	2.13 (1.43, 3.15)
Total sedentary time, hrs/day	2.85 (1.58, 5.15)	2.86 (1.51, 5.42)	2.96 (1.93, 4.52)
TV viewing time, hrs/day	4.20 (2.00, 8.80)	3.01 (1.46, 6.22)	3.75 (2.29, 6.13)
Daily computer and video-game use, hrs/day	8.04 (3.72, 17.38)	2.70 (1.10, 6.61)	3.37 (2.00, 5.67)
Homework and reading, hrs/day	3.14 (1.51, 6.54)	1.68 (0.74, 3.81)[a]	2.25 (1.34, 3.80)
Craft time, hrs/day	2.47 (1.17, 5.23)	1.90 (0.90, 3.99)[a]	2.51 (1.39, 4.54)

All analyses were adjusted for the following covariates: age at baseline, ethnicity, socioeconomic status and arm of WAVES study. Gender was also adjusted for in analyses conducted on the entire sample. For analyses conducted by gender, separate gender-specific quartile cut-offs were used.

[a]All Odds Ratios were significant at the $p<0.05$ level except those marked with [a].

[b] For percentage meeting UK MVPA recommendations, quartiles were not used and odds ratios presented refer to odds of a child who carries out the recommended MVPA at baseline maintaining this at follow-up 2, compared with children who do not meet the MVPA recommendations at baseline.

Table 3.5 Likelihood of maintaining levels of activity from baseline to follow-up (i.e. likelihood of those in the lowest activity and sedentary quartile at baseline staying in the same quartile at follow-up 2, compared to children in the highest three quartiles at baseline).			
	Boys **Odds Ratio (95% CI)**	**Girls** **Odds Ratio (95% CI)**	**Overall sample** **Odds Ratio (95% CI)**
MVPA, mins/day	2.20 (1.21, 4.00)	1.62 (0.85, 3.06)[a]	1.64 (1.05, 2.54)
PAEE, KJ/Kg/day	4.19 (2.21, 7.94)	5.99 (3.02, 11.90)	5.91 (3.73, 9.37)
Total sedentary time, hrs/day	2.42 (1.36, 4.32)	3.00 (1.61, 5.62)	2.61 (1.72, 3.98)
TV viewing time, hrs/day	1.33 (0.69, 2.58)[a]	4.41 (2.33, 8.33)	2.53 (1.64, 3.92)
Computer and video-game use, hrs/day	2.95 (1.53, 5.68)	2.50 (1.17, 5.38)	4.43 (2.70, 7.26)
Homework and reading, hrs/day	3.18 (1.62, 6.24)	2.17 (1.18, 3.98)	2.33 (1.48, 3.67)
Craft time, hrs/day	5.85 (2.59, 13.23)	2.58 (1.15, 5.81)	3.26 (1.91, 5.57)

All analyses were adjusted for the following covariates: age at baseline, ethnicity, socioeconomic status and arm of WAVES study. Gender was also adjusted for in analyses conducted on the entire sample. For analyses conducted by gender, separate gender-specific quartile cut-offs were used.
[a]All Odds Ratios were significant at the $p<0.05$ level except those marked with [a].

Table 3.6 Comparison of the socio-demographic and anthropometric characteristics of children who maintained the ≥60 minutes of MVPA per day UK recommendation from baseline to follow-up 2 with those children who carried out ≥60 minutes of MVPA per day at baseline, but no longer did at follow-up 2.

	Maintained ≥60 mins of MVPA per day, n (%)	**Did not maintain ≥60 mins of MVPA per day, n (%)**	**p-value[a]**
Total	101 (37.0)	172 (63.0)	
Gender			
Male	73 (43.7)	94 (56.3)	**<0.01**
Female	28 (26.4)	78 (73.6)	
Ethnicity			
White British	61 (44.9)	75 (55.1)	
South Asian	19 (24.4)	59 (75.6)	**0.03**
African Caribbean	6 (40.0)	9 (60.0)	
Other	15 (34.9)	28 (65.1)	
Socioeconomic group			
1=Most deprived	44 (31.7)	95 (68.3)	
2	20 (38.5)	32 (61.5)	
3	12 (40.0)	18 (60.0)	0.36
4	13 (52.0)	12 (48.0)	
5=Least deprived	10 (40.0)	15 (60.0)	
Weight status at baseline			
Normal/Underweight	83 (36.7)	143 (63.3)	0.84
Overweight/Obese	18 (38.3)	29 (61.7)	

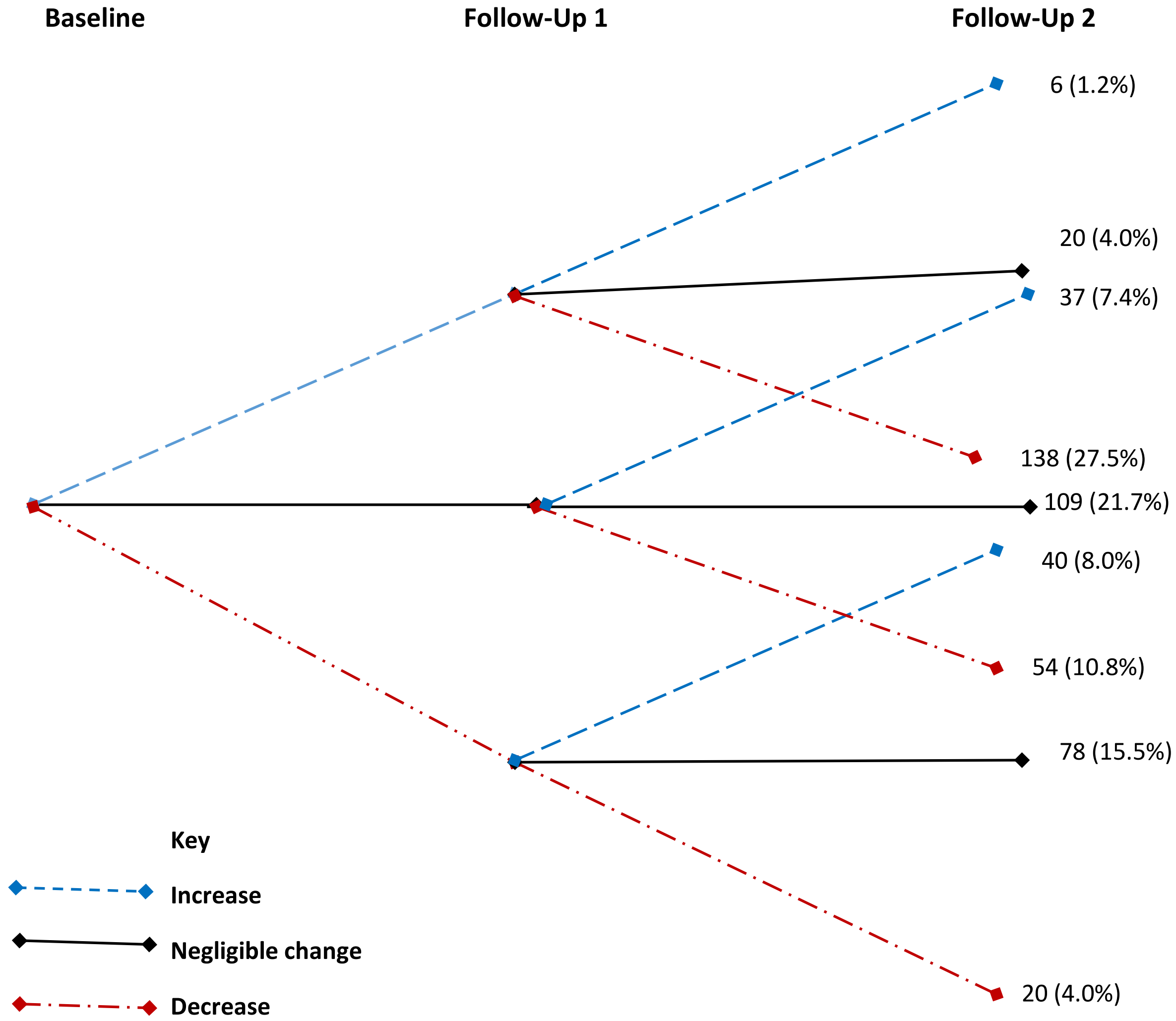
[a] Pearson's χ^2-test was used to compare the proportion of children who maintained and did not maintain MVPA between the different ethnic groups, socioeconomic groups, by gender and by weight status. Bold font represents statistical significance at the p=<0.05 level.

Figures 3.3, 3.4 and 3.5 display the percentage of children in each of the nine categories of change for MVPA, PAEE and total sedentary time between baseline and follow-up 2. Detailed information about how these nine categories were obtained was presented in Section 2.9.1. As can be seen in Figure 3.3, only a small percentage of children (4%) showed a constant decrease in MVPA. However, this was greater than the percentage of children consistently increasing their MVPA levels (1%). It was much more common to show an increase and then a decrease (28%), a decrease and then a negligible change

(16%) or a negligible change between both time-points (22%). Similar patterns can be seen in Figure 3.4 for PAEE. However, there was a higher proportion of children who showed a negligible change followed by a decrease in PAEE levels compared with MVPA (22% versus 11%). Figure 3.5 shows the percentages for total sedentary time. As can be seen, the highest number of children showed a decrease followed by an increase in total sedentary time (36%), a constant increase (14%), or a negligible change followed by an increase (17%). Just 3% showed a consistent decrease in the amount of time spent being sedentary.

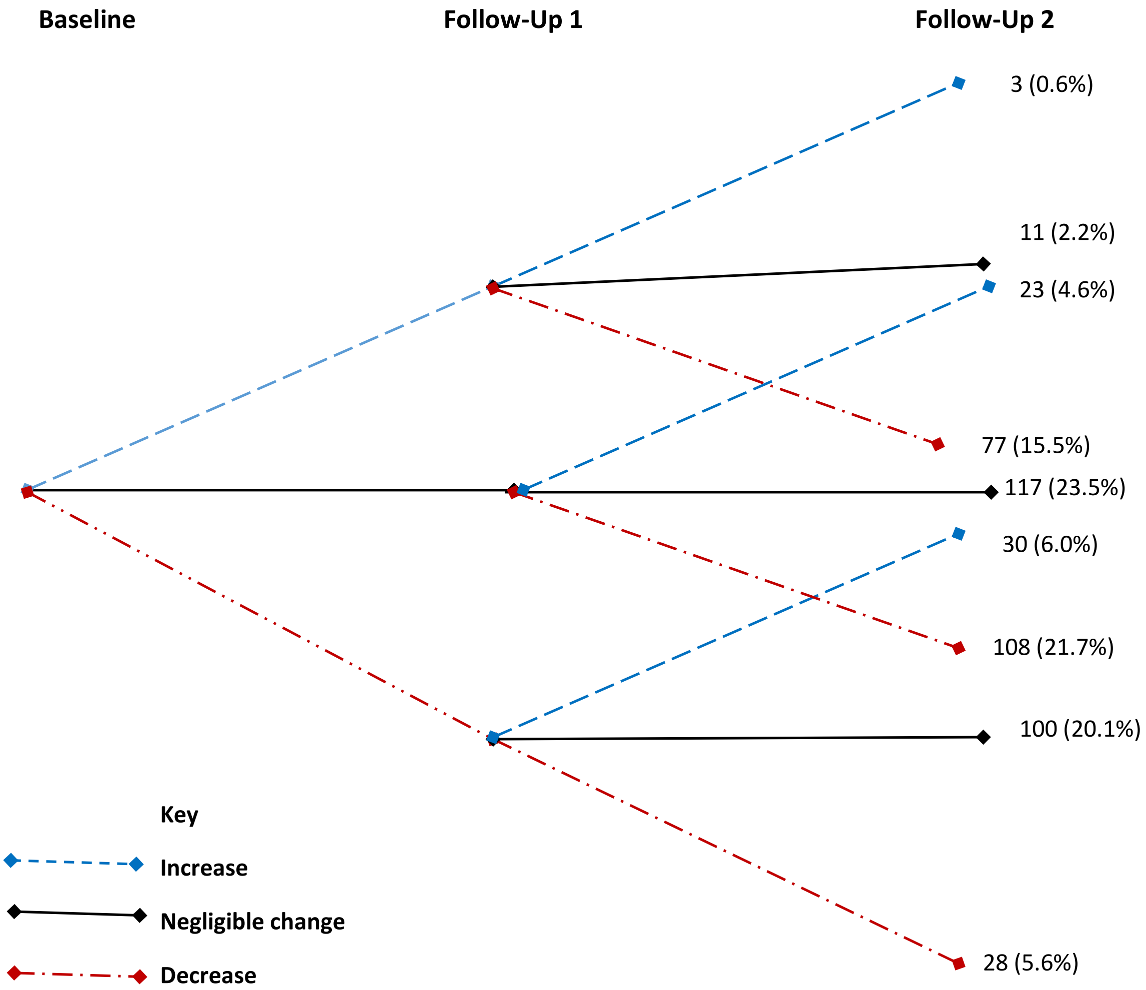
Overall, the proportion of children showing a decrease in MVPA and PAEE throughout the study period was 66% and 80% respectively, whilst the overall total sedentary time increased in 74% of children.

Figure 3.3 The number and percentage of children in each category of change for MVPA.



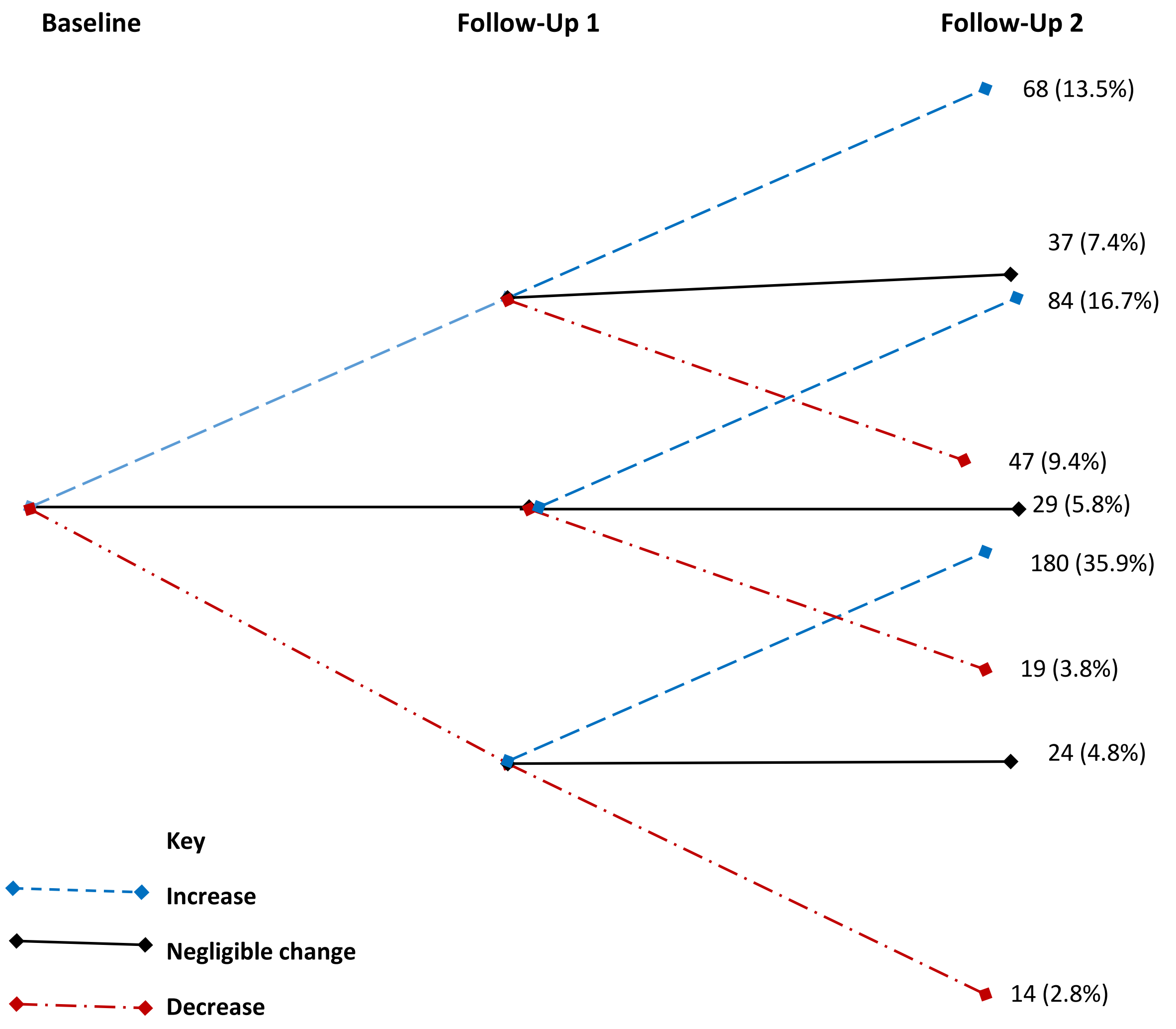
Negligible change boundaries for MVPA were defined as between -20 and +20 minutes of change between each data collection point.

Figure 3.4 The number and percentage of children in each category of change for PAEE.



Negligible change boundaries for PAEE were defined as between -15 and +15 kJ/Kg/day of change between each data collection point.

Figure 3.5 The number and percentage of children in each category of change for total sedentary time.



Negligible change boundaries for total sedentary time were defined as between -45 minutes and +45 minutes of change between each data collection point.

3.5 The change in physical activity and sedentary behaviour from 5-6 years to 8-9 years

Table 3.7 shows the unadjusted and adjusted (for study arm, socioeconomic status and ethnicity) mean change in each of the measures of physical activity and sedentary behaviour per year of age increase.

Between 5-6 years and 8-9 years, girls decreased their level of MVPA slightly more than boys (a decrease of 7.4 minutes/day/year versus 6.7 minutes/day/year). In contrast, the decrease in PAEE was slightly greater for boys than girls (a decrease of 6.2 kJ/Kg/day/year versus 5.9 kJ/Kg/day/year). However, neither of these gender differences were statistically significant.

Total sedentary time increased more for boys compared with girls (34.8 minutes/day/year versus 28.8 minutes/day/year). However again, this gender difference was non-significant. All of the separate sedentary behaviours increased, except the time spent doing craft which showed a small decrease. Interestingly, both TV viewing time and the time spent on homework/reading showed very small increases per year of age increase between 5-6 years and 8-9 years (TV viewing increased for boys at a rate of 5 minutes/day/year and for girls at a rate of 7 minutes/day/year. Homework/reading time increased by 3 minutes/day/year for both genders). In contrast, the time spent using the computer and playing video-games increased by a larger amount for both boys and girls (an increase of 13 minutes/day/year for boys and 10 minutes/day/year for girls). This suggests that computer and video-game use made the largest contribution to the increase in total sedentary time compared with the other sedentary behaviours that were measured.

Table 3.7 Unadjusted and adjusted mean change in activity characteristics per year of age increase from baseline (5-6 years) to follow-up 2 (8-9 years). Presented for boys and girls, and the mean difference in change between boys and girls.

	Boys mean change per year of age increase		**Girls mean change per year of age increase**		**Mean difference in change (boys-girls) (95% CI)**	
	Unadjusted Mean (SD)	Adjusted Mean (SE)	Unadjusted Mean (SD)	Adjusted Mean (SE)	Unadjusted	Adjusted
MVPA, mins/day	-5.98 (22.34)	-6.74 (1.46)	-6.40 (16.64)	-7.37 (1.55)	0.42 (-2.85, 3.68)	0.63 (-2.67, 3.93)
PAEE, KJ/Kg/day	-6.08 (9.39)	-6.18 (0.62)	-5.70 (7.31)	-5.87 (0.67)	-0.38 (-1.78, 1.02)	-0.31 (-1.72, 1.11)
Total sedentary time, hrs/day	0.52 (0.94)	0.58 (0.06)	0.41 (0.79)	0.48 (0.07)	0.11 (-0.03, 0.26)	0.10 (-0.05, 0.24)
TV viewing time, hrs/day	0.04 (0.48)	0.09 (0.05)	0.06 (0.49)	0.11 (0.05)	-0.03 (-0.11, 0.06)	-0.02 (-0.11, 0.07)
Computer and video-game use, hrs/day	0.24 (0.44)	0.22 (0.04)	0.17 (0.42)	0.16 (0.04)	0.06 (-0.01, 0.15)	0.06 (-0.02, 0.14)
Homework and reading, hrs/day	0.06 (0.29)	0.05 (0.03)	0.07 (0.32)	0.05 (0.03)	0.00 (-0.06, 0.05)	0.00 (-0.06, 0.06)
Craft time, hrs/day	-0.07 (0.30)	-0.08 (0.03)	-0.07 (0.31)	-0.08 (0.03)	0.00 (-0.06, 0.06)	0.00 (-0.06, 0.06)

A positive mean difference in change represents that the change for girls is more negative than for boys.
Adjustment was made for the following covariates: arm of WAVES study, socioeconomic status and ethnicity.
No comparisons between girls and boys were statistically significant at the p<0.05 level.

3.6 Sensitivity analysis

All analyses with total sedentary time were repeated, using the variable where parent-reported sleep duration had been subtracted from total sedentary time. The overall patterns remained unchanged with sedentary time (with sleep subtracted) increasing over the study period (an increase of 32 minutes/day/year for boys and 27 minutes/day/year for girls, data not shown) and weak tracking from baseline to follow-up 2 (r=0.17, data not shown).

3.7 Summary

In summary, this chapter has presented the results from analyses relating to how physical activity and sedentary behaviour levels change and track between the ages of 5-6 years and 8-9 years. As expected, both PAEE and MVPA levels decreased over the study period and the amount of time spent being sedentary increased at a rate of 35 minutes/day/year for boys and 29 minutes/day/year for girls. The time spent in each of the separately measured sedentary behaviours increased except for craft time, which showed a small decrease. There were no significant differences between boys and girls in the rate of change per year of age increase for each of the measured physical activity and sedentary behaviour variables. However, boys consistently carried out more MVPA compared with girls, whereas boys and girls showed more similar total sedentary time throughout the study period.

Among the sedentary behaviours assessed, TV viewing time tracked most strongly over the primary school period. Each of the individual sedentary behaviours tracked moderately strongly, and generally slightly stronger in boys compared with girls (especially video-game and computer use). However, total sedentary time tracked relatively weakly, especially when compared to PAEE, which was the measure that overall, showed the strongest degree of tracking. In contrast, the number of minutes of MVPA carried out per day at 5-6 years only weakly correlated with MVPA levels at 8-9 years.

CHAPTER 4: THE ASSOCIATION BETWEEN CHANGE IN PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR, AND ADIPOSITY IN MIDDLE CHILDHOOD

4.1 Aims and objectives

This chapter presents the results from the analyses conducted to fulfil the primary aim of determining whether changes in measures of physical activity and sedentary behaviour between 5-6 years and 8-9 years were associated with various measures of adiposity at 8-9 years. Secondary aims were to test whether any associations of physical activity and sedentary behaviour with adiposity were independent of one another and to examine whether there were any differences in these associations between boys and girls.

Specific objectives for this chapter were to:

- Describe the levels of adiposity at each time-point in the overall sample and by gender.
- Examine longitudinal associations between the change in time spent undertaking physical activity and sedentary behaviours, and measures of adiposity at follow-up 2, adjusting for baseline adiposity and the relevant baseline measure of physical activity/sedentary behaviour, and further adjusting for potential confounding factors.
- Explore differences in these associations between boys and girls.

From the review of previous research presented in Chapter 1, the following hypotheses have been developed:

- The change in time spent in MVPA will have a greater impact on adiposity than the change in total physical activity(75-78).
- Physical activity measures will have a stronger association with BF% compared with BMI z-score(67).

- The change in TV viewing time will have a greater influence on adiposity compared with other sedentary behaviours(66,82).
- The association of physical activity with adiposity will be stronger in boys than girls(70,77).

4.2 Participant characteristics

The socio-demographic characteristics of the children that have been included in these analyses have previously been presented in Table 3.1. Information about the numbers of children who provided Actiheart and parental questionnaire data can be found in Section 3.2. The number of children with valid adiposity data decreased as the study progressed. At baseline, 95% of children had adiposity measurements recorded (n=1396). However, the proportion of children with these measurements fell to 85% (n=1252) at follow-up 1 and 78% (n=1146) at follow-up 2. At all three time-points 500 children (34% of overall sample) had both Actiheart and adiposity measurements, and 522 children (36% of overall sample) provided subjective sedentary behaviour information from the parental questionnaire in addition to adiposity measurements.

4.3 Descriptive statistics

Table 4.1 shows the mean values for each measure of adiposity at 5-6 years, 7-8 years and 8-9 years. It also shows the proportion of children at each data collection point classified as overweight/obese based on the UK 1990 reference centile curves(166). All measures of adiposity showed a significant increase between 5-6 years and 8-9 years. For example, mean waist circumference (WC) increased from 56cm to 63cm (p=<0.001), whilst mean BF% increased from 20.5% to 22.0% (p=<0.001). The trend for adiposity measures to increase as the children became older is reflected in the proportion of children classified as overweight/obese. At age 5-6 years, 21% of children were overweight/obese, and this increased to 27% at 7-8 years and 32% at 8-9 years.

Of the four adiposity measures included in the analyses presented later in this chapter (BMI z-score, waist circumference z-score, BF% and the sum of skinfold thickness), waist circumference z-score was the only measure that did not differ significantly between boys and girls at all 3 time-points. Although the higher mean BMI z-score in boys compared with girls was non-significant at baseline, the differences became larger and statistically significantly at follow-up 1 (7-8 years) and follow-up 2 (8-9 years). Similarly the proportion of boys classified as overweight/obese was always higher than the proportion of girls, and the gap between sexes increased over time. In contrast, girls showed significantly higher mean values for both BF% and the sum of skinfold thickness at each time-point.

Table 4.1: Anthropometric characteristics of the study sample and by gender. Mean value and standard deviation displayed unless otherwise stated by n (%).

	Baseline (5-6 years)			**Follow-Up 1 (7-8 years)**			**Follow-Up 2 (8-9 years)**		
	Boys n=720 (51.6%)	**Girls** n=676 (48.4%)	**Total** n=1396	**Boys** n=641 (51.2%)	**Girls** n=611 (48.8%)	**Total** n=1252	**Boys** n=589 (51.4%)	**Girls** n=557 (48.6%)	**Total** n=1146
BMI	16.19 (2.44)	16.05 (2.24)	16.12 (2.35)	16.78 (2.83)	16.68 (2.75)	16.73 (2.79)	17.62 (3.40)	17.50 (3.17)	17.56 (3.29)
BMI z-score	+0.24 (1.31)	+0.14 (1.12)	+0.19 (1.22)	**+0.36 (1.38)**	**+0.19 (1.21)**	+0.28 (1.3)	**+0.46 (1.39)**	**+0.25 (1.25)**	+0.36 (1.33)
Waist circumference, cm	55.92 (5.78)	55.82 (6.51)	55.87 (6.14)	59.60 (7.79)	59.46 (7.90)	59.54 (7.84)	62.63 (9.26)	62.75 (9.16)	62.69 (9.21)
Waist circumference z-score	+0.68 (1.24)	+0.74 (1.25)	+0.71 (1.25)	+0.96 (1.34)	+0.95 (1.34)	+0.96 (1.34)	+0.95 (1.32)	+1.08 (1.29)	+1.01 (1.31)
Body fat percentage (%)	**20.51 (4.95)**	**21.76 (5.55)**	21.12 (5.28)	**20.35 (6.56)**	**22.29 (6.33)**	21.30 (6.52)	**20.90 (7.78)**	**23.21 (6.72)**	22.02 (7.37)
Sum of skinfold thickness, mm	**29.11 (12.40)**	**35.23 (15.26)**	32.01 (14.16)	**32.81 (17.27)**	**39.54 (16.92)**	36.06 (17.42)	**36.63 (20.71)**	**43.55 (19.39)**	39.71 (20.41)
Proportion of children classified as overweight/obese, **n (%)**[a]	**168 (23.3)**	**127 (18.9)**	295 (21.2)	**186 (29.1)**	**146 (24.0)**	332 (26.6)	**213 (36.2)**	**150 (27.0)**	363 (31.7)

Note: Independent samples t-tests were used to test for mean differences between boys and girls at baseline and each follow-up time-point. Repeated measures ANOVA was used to test for significant differences in each adiposity measure for the overall sample, boys and girls across the three time-points. Significance was taken to be $p<0.05$.

Bold font represents a significant difference between boys and girls at baseline, follow-up 1 or follow-up 2.

All adiposity measures significantly increased across the three time-points in the overall sample, in boys and in girls.

[a] Weight category from calculation of BMI z-score using UK 1990 reference centile curves and cut-offs used for population monitoring. Pearson's χ^2-test was used to test for significant differences between boys and girls in the proportion of children classified as overweight/obese. Repeated measures ANOVA were not performed for the proportion of children classified as overweight/obese.

4.4 The association between changes in physical activity from ages 5-6 to 8-9 years and adiposity at age 8-9 years

Multilevel linear regression analyses exploring the association between a decrease in MVPA and PAEE and measures of adiposity are shown in Table 4.2. As hypothesised, a decrease in MVPA had a greater impact on the adiposity measures than total physical activity (PAEE) did. A decrease in MVPA was significantly associated with increase in all four measures of adiposity in fully adjusted models. The regression coefficients showed that a decrease in MVPA between baseline and follow-up 2 was associated with a significant increase in adiposity. In fully adjusted models, a 30 minute/day decrease in MVPA between the ages of 5-6 years and 8-9 years was associated with an increase in BMI z-score of 0.08 (95%CI=0.02, 0.13, p=0.01), a 0.08 increase in waist circumference z-score (95%CI=0.01, 0.15, p=0.04), a 0.41% increase in BF% (95%CI=0.03, 0.80, p=0.04) and a 1.28 mm increase in the sum of skinfold thickness (95%CI=0.14, 2.43, p=0.03). These models had been adjusted for the change in total sedentary time between baseline and follow-up 2, meaning that the observed associations are independent of the change in time that a child spends being sedentary.

The significant associations between a decrease in MVPA and BMI z-score, waist circumference z-score and skinfold thicknesses were present across all three models. However this was not the case for BF%. In Model 1 (adjusted for the baseline adiposity measure and baseline MVPA), the association between a decrease in MVPA and BF% was significant. Adjustment for socio-demographic variables and intervention arm in Model 2 caused this association to become attenuated. However in Model 3, once the increase in total sedentary time was adjusted for, the association was accentuated and became significant again. This implies that the change in total sedentary time is a confounder in this association.

A decrease in PAEE was significantly associated with higher BF% and the sum of skinfold thickness in Model 1. However, in the fully adjusted model which included socio-demographic, intervention arm and change in total sedentary time covariates, although the magnitude of effect remained similar, the association with sum of skinfold thickness was no longer statistically significant. A decrease in PAEE of 10 kJ/Kg/day produced a significant increase in BF% of 0.31% (95%CI=0.08, 0.54, p=0.01).

Table 4.2 Multilevel linear regression analyses conducted on the study sample with follow-up 2 adiposity as outcome variable. Unstandardised regression coefficients (B) of models for each decrease in physical activity parameter from baseline to follow-up 2.			
Outcome/predictor variable	**Model 1[a] B coefficient (95% CI)**	**Model 2[b] B coefficient (95% CI)**	**Model 3[c] B coefficient (95% CI)**
Predictor: Decrease in MVPA, 30 mins/day			
Follow-Up 2 BMI z-score	**0.05 (0.01, 0.09)**	**0.05 (0.01, 0.10)**	**0.08 (0.02, 0.13)**
Follow-Up 2 WC z-score	**0.07 (0.02, 0.13)**	**0.06 (0.01, 0.11)**	**0.08 (0.01, 0.15)**
Follow-Up 2 BF%	**0.35 (0.06, 0.64)**	0.21 (-0.09, 0.50)	**0.41 (0.03, 0.80)**
Follow-Up 2 Skinfold thicknesses, mm	**1.26 (0.43, 2.09)**	**1.12 (0.27, 2.00)**	**1.28 (0.14, 2.43)**
Predictor: Decrease in PAEE, 10 kJ/Kg/day			
Follow-Up 2 BMI z-score	0.02 (-0.01, 0.05)	0.02 (-0.01, 0.05)	0.03 (0.00, 0.07)
Follow-Up 2 WC z-score	0.02 (-0.01, 0.05)	0.01 (-0.02, 0.04)	0.00 (-0.04, 0.05)
Follow-Up 2 BF%	**0.27 (0.09, 0.44)**	0.17 (-0.01, 0.36)	**0.31 (0.08, 0.54)**
Follow-Up 2 Skinfold thicknesses, mm	**0.71 (0.18, 1.24)**	**0.65 (0.11, 1.19)**	0.64 (-0.05, 1.32)

[a]Adjusted for the appropriate measure of adiposity and physical activity at baseline. The pupils' school was added as a random effect.
[b] Further adjusted for age at baseline, gender, ethnicity, socioeconomic status and the arm of the WAVES study that the pupil was in.
[c] Further adjusted for the increase in total sedentary time between baseline and follow-up 2.
Bold font represents statistical significance, p<0.05.

4.5 The association between changes in sedentary behaviour from ages 5-6 to 8-9 years and adiposity at age 8-9 years

Table 4.3 presents the results from the multilevel linear regression models where the predictor variables were an increase in the different sedentary behaviour variables between baseline and follow-up 2, and the outcome variables were the measures of follow-up 2 adiposity. Overall, there were fewer significant associations between changes in sedentary behaviours and adiposity, compared with the physical activity variables (outlined in Section 4.4).

The only measure of sedentary behaviour that showed a significant association with adiposity was an increase in TV viewing time, which was significantly associated with BMI z-score in all 3 models. In the fully adjusted models (adjusted for baseline BMI z-score, baseline TV viewing time, socio-demographic variables, intervention arm and the decrease in PAEE), an increase in TV viewing time of 1 hour/day between the ages of 5-6 years and 8-9 years was associated with an increase in BMI z-score at 8-9 years of 0.06 (95%CI=0.01, 0.12, p=0.04). An increase in TV viewing time was significantly associated with an increased waist circumference z-score in Models 1 and 2. However, the addition of the decrease in PAEE in Model 3 caused this effect to become attenuated. The regression coefficients for the BF% and skinfold thicknesses models in which an increase in TV viewing time is the predictor variable, are in the same direction as BMI z-score and waist circumference z-score (i.e. an increase in TV viewing producing an increase in adiposity). However, these coefficients do not reach significance.

No significant associations were found between an increase in the total sedentary time and computer/video-game use, and the adiposity measures. Although non-significant, the point estimates of the regression coefficients for these two variables were generally in the opposite direction to that expected (i.e. an increase in total sedentary time and computer/video-game use associated with a decrease in adiposity). There were no significant associations between increases in the time spent in other sedentary behaviours (reading, homework and craft) and adiposity measures. However, the direction of the regression coefficients were generally as expected (i.e. an increase in the time spent carrying out these sedentary behaviours is associated with increased adiposity).

Table 4.3 Multilevel linear regression analyses conducted on the study sample with follow-up 2 adiposity as outcome variable. Unstandardised regression coefficients (B) of models for each increase in sedentary behaviour parameter from baseline to follow-up 2.			
Outcome/predictor variable	**Model 1[a] B coefficient (95% CI)**	**Model 2[b] B coefficient (95% CI)**	**Model 3[c] B coefficient (95% CI)**
Predictor: Increase in total sedentary time, hrs/day			
Follow-Up 2 BMI z-score	0.00 (-0.03, 0.03)	-0.01 (-0.04, 0.02)	-0.02 (-0.05, 0.02)
Follow-Up 2 WC z-score	-0.01 (-0.04, 0.03)	-0.01 (-0.05, 0.02)	-0.01 (-0.05, 0.03)
Follow-Up 2 BF%	-0.07 (-0.25, 0.12)	-0.09 (-0.28, 0.09)	-0.23 (-0.45, 0.00)
Follow-Up 2 Skinfold thicknesses, mm	0.23 (-0.34, 0.80)	0.17 (-0.40, 0.74)	-0.09 (-0.78, 0.61)
Predictor: Increase in TV viewing time, hrs/day			
Follow-Up 2 BMI z-score	**0.08 (0.03, 0.13)**	**0.08 (0.03, 0.13)**	**0.06 (0.01, 0.12)**
Follow-Up 2 WC z-score	**0.09 (0.03, 0.15)**	**0.09 (0.03, 0.15)**	0.07 (0.00, 0.14)
Follow-Up 2 BF%	0.27 (-0.08, 0.62)	0.26 (-0.09, 0.61)	0.15 (-0.24, 0.55)
Follow-Up 2 Skinfold thicknesses, mm	0.49 (-0.55, 1.54)	0.42 (-0.62, 1.44)	0.75 (-0.40, 1.89)
Predictor: Increase in computer and video-game use, hrs/day			
Follow-Up 2 BMI z-score	0.01 (-0.05, 0.07)	0.00 (-0.06, 0.06)	-0.02 (-0.08, 0.05)
Follow-Up 2 WC z-score	-0.03 (-0.10, 0.04)	-0.02 (-0.09, 0.05)	-0.05 (-0.13, 0.03)
Follow-Up 2 BF%	-0.18 (-0.57, 0.21)	-0.10 (-0.50, 0.30)	-0.10 (-0.52, 0.32)
Follow-Up 2 Skinfold thicknesses, mm	-0.03 (-1.23, 1.16)	-0.11 (-1.31, 1.09)	0.09 (-1.24, 1.42)
Predictor: Increase in other sedentary behaviours, hrs/day			
Follow-Up 2 BMI z-score	0.04 (-0.02, 0.11)	0.06 (-0.01, 0.13)	0.01 (-0.07, 0.09)
Follow-Up 2 WC z-score	0.00 (-0.08, 0.08)	0.00 (-0.08, 0.08)	-0.04 (-0.14, 0.05)
Follow-Up 2 BF%	0.16 (-0.29, 0.62)	0.09 (-0.37, 0.55)	0.00 (-0.50, 0.50)
Follow-Up 2 Skinfold thicknesses, mm	0.84 (-0.50, 2.18)	0.68 (-0.64, 2.01)	0.75 (-0.76, 2.25)

[a]Adjusted for the appropriate measure of adiposity and sedentary behaviour at baseline. The pupils' school was added as a random effect.
[b]Further adjusted for age at baseline, gender, ethnicity, socioeconomic status and the arm of the WAVES study that the pupil was in.
[c]Further adjusted for the decrease in PAEE between baseline and follow-up 2.
Bold font represents statistical significance, p<0.05.

4.6 Gender differences in the association between changes in physical activity from ages 5-6 to 8-9 years and adiposity at 8-9 years

Separate regression models for boys and girls, presented in Table 4.4, suggest that a decrease in MVPA between baseline and follow-up 2 had a greater impact on the adiposity measures at follow-up 2 in girls compared with boys. In fully adjusted models, a decrease in MVPA was significantly associated with an increase in all four measures of adiposity in girls, whereas none of the associations in boys were significant. In girls, for every 30 minute/day decrease in MVPA between the ages of 5-6 and 8-9 years, BMI z-score increased by 0.13 (95%CI=0.04, 0.22, p=<0.01), waist circumference z-score increased by 0.16 (95%CI=0.05, 0.27, p=<0.01), BF% increased by 0.65% (95%CI=0.11, 1.20, p=0.02) and skinfold thicknesses increased by 2.31 (95%CI=0.32, 4.29, p=0.02). A decrease in MVPA was significantly associated with an increase in skinfold thicknesses in boys in Model 1 (adjusted for baseline skinfold thicknesses and baseline MVPA) and Model 2 (adjusted for socio-demographic variables and intervention arm). However, further adjustment in boys (for the change in total sedentary time) attenuated this association.

On examination of the separate associations between decreasing total physical activity and adiposity in boys and girls, a decrease in total physical activity was associated with an increase in the sum of skinfold thickness in all three models, in boys only. However, this effect size was small – in fully adjusted models, each 10 kJ/Kg/day decrease in PAEE caused an increase in the sum of skinfold thickness in boys of 0.94 mm (95%CI=0.16, 1.71, p=0.02).

Table 4.4 Multilevel linear regression analyses conducted separately on boys and girls with follow-up 2 adiposity as outcome variable. Unstandardised regression coefficients (B) of models for each decrease in physical activity parameter from baseline to follow-up 2.

Outcome/predictor variable	**Boys**			**Girls**		
	Model 1[a] B coefficient (95% CI)	**Model 2[b] B coefficient (95% CI)**	**Model 3[c] B coefficient (95% CI)**	**Model 1[a] B coefficient (95% CI)**	**Model 2[b] B coefficient (95% CI)**	**Model 3[c] B coefficient (95% CI)**
Predictor: Decrease in MVPA, 30 mins/day						
Follow-Up 2 BMI z-score	0.05 (-0.01, 0.11)	0.04 (-0.01, 0.10)	0.04 (-0.04, 0.11)	**0.08 (0.01, 0.15)**	**0.08 (0.01, 0.16)**	**0.13 (0.04, 0.22)**
Follow-Up 2 WC z-score	0.04 (-0.02, 0.11)	0.04 (-0.03, 0.10)	0.01 (-0.08, 0.11)	**0.12 (0.03, 0.21)**	**0.12 (0.03, 0.21)**	**0.16 (0.05, 0.27)**
Follow-Up 2 BF%	0.26 (-0.12, 0.64)	0.20 (-0.19, 0.58)	0.25 (-0.29, 0.80)	0.35 (-0.10, 0.80)	0.35 (-0.11, 0.81)	**0.65 (0.11, 1.20)**
Follow-Up 2 Skinfold thicknesses, mm	**1.07 (0.09, 2.04)**	**1.05 (0.06, 2.04)**	0.75 (-0.64, 2.14)	**1.79 (0.21, 3.36)**	1.62 (0.00, 3.23)	**2.31 (0.32, 4.29)**
Predictor: Decrease in PAEE, 10 kJ/Kg/day						
Follow-Up 2 BMI z-score	0.04 (0.00, 0.07)	0.03 (0.00, 0.07)	0.03 (-0.01, 0.08)	0.01 (-0.04, 0.06)	0.01 (-0.04, 0.05)	0.02 (-0.04, 0.08)
Follow-Up 2 WC z-score	0.00 (0.00, 0.01)	0.01 (-0.03, 0.05)	0.00 (-0.05, 0.05)	0.00 (0.00, 0.01)	0.01 (-0.05, 0.07)	0.02 (-0.06, 0.09)
Follow-Up 2 BF%	**0.27 (0.03, 0.50)**	0.21 (-0.03, 0.44)	0.28 (-0.02, 0.58)	0.19 (-0.09, 0.47)	0.16 (-0.13, 0.45)	0.36 (0.00, 0.72)
Follow-Up 2 Skinfold thicknesses, mm	**0.99 (0.37, 1.60)**	**0.97 (0.35, 1.59)**	**0.94 (0.16, 1.71)**	0.29 (-0.73, 1.31)	0.15 (-0.91, 1.21)	0.02 (-1.32, 1.37)

[a]Adjusted for the appropriate measure of adiposity and physical activity at baseline. The pupils' school was added as a random effect.
[b]Further adjusted for age at baseline, ethnicity, socioeconomic status and the arm of the WAVES study that the pupil was in.
[c]Further adjusted for the increase in total sedentary time between baseline and follow-up 2.
Bold font represents statistical significance, p<0.05.

4.7 Gender differences in the association between changes in sedentary behaviour from ages 5-6 to 8-9 years and adiposity at age 8-9 years

The subgroup analyses for boys and girls exploring associations between the change in sedentary behaviour variables and adiposity are shown in Table 4.5. Similar to findings in the total sample, when boys and girls were considered separately, the only sedentary behaviour that showed a significant association with adiposity was an increase in TV viewing time. However, the measure of adiposity that was associated with an increase in TV viewing time, was different for boys and girls. In all three models in boys, an increase in TV viewing time was associated with a significant increase in waist circumference z-score. In the fully adjusted model, an increase in TV viewing time of 1 hour/day between the ages of 5-6 and 8-9 years, was associated with an increase in waist circumference z-score of 0.12 (95%CI=0.01, 0.22, p=0.03). In girls, an increase in TV viewing time was associated with a significant increase in BMI z-score in Models 1 and 2. However, in Model 3 when the change in PAEE had been adjusted for, this effect became attenuated. This would suggest that the association between increased TV viewing time and BMI z-score in girls is not independent of the change in the total physical activity that a child carries out (i.e. girls who increase their TV viewing are displacing physical activity which therefore leads to an increase in their BMI z-score).

Table 4.5 Multilevel linear regression analyses conducted separately on boys and girls with follow-up 2 adiposity as outcome variable. Unstandardised regression coefficients (B) of models for each decrease in sedentary behaviour parameter from baseline to follow-up 2.

Outcome/predictor variable	Boys			Girls		
	Model 1[a] B coefficient (95% CI)	Model 2[b] B coefficient (95% CI)	Model 3[c] B coefficient (95% CI)	Model 1[a] B coefficient (95% CI)	Model 2[b] B coefficient (95% CI)	Model 3[c] B coefficient (95% CI)
Predictor: Increase in total sedentary time, hrs/day						
Follow-Up 2 BMI z-score	0.01 (-0.03, 0.04)	0.01 (-0.03, 0.05)	0.00 (-0.04, 0.05)	-0.02 (-0.07, 0.02)	-0.03 (-0.07, 0.02)	-0.04 (-0.10, 0.01)
Follow-Up 2 WC z-score	0.00 (-0.04, 0.04)	0.00 (-0.04, 0.04)	0.01 (-0.04, 0.06)	-0.02 (-0.07, 0.04)	-0.03 (-0.08, 0.03)	-0.03 (-0.10, 0.04)
Follow-Up 2 BF%	-0.01 (-0.26, 0.24)	-0.02 (-0.27, 0.23)	-0.11 (-0.42, 0.19)	-0.10 (-0.37, 0.18)	-0.15 (-0.42, 0.13)	-0.31 (-0.65, 0.03)
Follow-Up 2 Skinfold thicknesses, mm	0.41 (-0.26, 1.08)	0.35 (-0.33, 1.02)	0.00 (-0.83, 0.83)	0.07 (-0.97, 1.10)	0.02 (-1.04, 1.08)	-0.10 (-1.40, 1.20)
Predictor: Increase in TV viewing time, hrs/day						
Follow-Up 2 BMI z-score	0.07 (-0.01, 0.14)	0.07 (-0.01, 0.14)	0.07 (-0.03, 0.16)	**0.09 (0.02, 0.16)**	**0.08 (0.02, 0.15)**	0.04 (-0.03, 0.12)
Follow-Up 2 WC z-score	**0.09 (0.01, 0.17)**	**0.09 (0.01, 0.17)**	**0.12 (0.01, 0.22)**	0.07 (-0.01, 0.16)	0.07 (-0.02, 0.16)	0.01 (-0.09, 0.12)
Follow-Up 2 BF%	0.27 (-0.26, 0.79)	0.21 (-0.30, 0.72)	0.14 (-0.47, 0.75)	0.28 (-0.19, 0.74)	0.22 (-0.24, 0.69)	0.05 (-0.44, 0.54)
Follow-Up 2 Skinfold thicknesses, mm	-0.29 (-1.67, 1.09)	-0.46 (-1.81, 0.89)	-0.36 (-1.89, 1.14)	1.36 (-0.16, 2.89)	1.06 (-0.50, 2.62)	1.34 (-0.31, 2.99)
Predictor: Increase in computer and video-game use, hrs/day						
Follow-Up 2 BMI z-score	-0.02 (-0.10, 0.06)	-0.03 (-0.18, 0.13)	-0.01 (-0.10, 0.08)	0.02 (-0.07, 0.10)	0.05 (-0.12, 0.21)	-0.03 (-0.14, 0.07)
Follow-Up 2 WC z-score	-0.04 (-0.12, 0.05)	-0.01 (-0.09, 0.08)	-0.01 (-0.12, 0.09)	-0.02 (-0.13, 0.09)	-0.03 (-0.14, 0.09)	-0.09 (-0.22, 0.04)
Follow-Up 2 BF%	-0.21 (-0.74, 0.33)	-0.12 (-0.65, 0.41)	-0.04 (-0.61, 0.54)	0.05 (-0.52, 0.63)	0.00 (-0.58, 0.58)	-0.17 (-0.81, 0.46)
Follow-Up 2 Skinfold thicknesses, mm	-0.28 (-1.65, 1.09)	0.13 (-1.24, 1.50)	0.60 (-0.93, 2.11)	0.51 (-1.72, 2.74)	-0.17 (-2.45, 2.12)	0.06 (-2.30, 2.43)
Predictor: Increase in other sedentary behaviours, hrs/day						
Follow-Up 2 BMI z-score	0.02 (-0.08, 0.12)	0.02 (-0.08, 0.12)	-0.04 (-0.17, 0.09)	0.08 (-0.01, 0.16)	0.08 (-0.01, 0.17)	0.01 (-0.09, 0.11)
Follow-Up 2 WC z-score	-0.06 (-0.17, 0.05)	-0.07 (-0.18, 0.05)	-0.11 (-0.25, 0.04)	0.05 (-0.06, 0.16)	0.04 (-0.07, 0.16)	-0.04 (-0.17, 0.09)
Follow-Up 2 BF%	0.39 (-0.26, 1.05)	0.11 (-0.57, 0.78)	-0.18 (-0.95, 0.59)	-0.07 (-0.68, 0.54)	-0.11 (-0.75, 0.52)	-0.12 (-0.77, 0.52)
Follow-Up 2 Skinfold thicknesses, mm	0.74 (-0.91, 2.39)	0.32 (-1.33, 1.98)	0.01 (-1.96, 1.98)	0.96 (-1.13, 3.05)	0.98 (-1.20, 3.16)	1.21 (-1.13, 3.54)

[a]Adjusted for the appropriate measure of adiposity and physical activity at baseline. The pupils' school was added as a random effect.
[b]Further adjusted for age at baseline, ethnicity, socioeconomic status and the arm of the WAVES study that the pupil was in.
[c]Further adjusted for the decrease in PAEE between baseline and follow-up 2.
Bold font represents statistical significance, p<0.05.

4.8 Sensitivity analysis

Analyses were repeated using the variable in which parent-reported sleep duration had been subtracted from the Actiheart-measured total sedentary time. An increase in sedentary time with sleep subtracted produced very similar results to an increase in total sedentary time. In the analyses conducted on the overall sample and by gender, the point estimates of the regression coefficients were extremely small and all results were non-significant. This was the case in all three models and with each measure of adiposity.

4.9 Summary

This chapter has presented the results of the analyses examining the individual associations between changes in physical activity and sedentary behaviour, and adiposity in children. A decrease in MVPA between the ages of 5-6 years and 8-9 years was significantly associated with an increased BMI z-score, waist circumference z-score, BF% and skinfold thicknesses at 8-9 years. These associations were independent of the change in time that a child spends being sedentary. It was hypothesised that MVPA has a greater impact on adiposity than total physical activity. These results support this by the fact that a decrease in MVPA was significantly associated with a greater number of adiposity measures compared to total physical activity, and that the associations were of greater magnitude. A decrease in MVPA was significantly associated with an increase in all four measures of adiposity in girls. However, in boys none of the measures of adiposity showed significant associations, suggesting that the association between decreased MVPA and increased adiposity is stronger in girls compared with boys. This finding does not support the prior hypothesis (outlined in Section 4.1), which predicted that any association found between MVPA and adiposity would be stronger in boys.

After all adjustments had been made, the only significant associations between the sedentary behaviours and adiposity, were that an increase in TV viewing time was significantly associated with an increase in BMI z-score in the overall sample and an increase in waist circumference z-score in boys only. This supports the hypothesis, that TV viewing time would have the greatest impact on adiposity when compared with other sedentary behaviours.

CHAPTER 5: DISCUSSION

This chapter summarises the key findings of the research that has been conducted for this thesis, and discusses these findings in relation to the research that has previously been carried out on the same topic areas. The implications of these findings for future intervention programmes aiming to reduce childhood overweight and obesity are then outlined. Finally, the strengths and limitations of this thesis are discussed and the conclusions of the thesis are presented.

5.1 Thesis summary

The aims of this thesis were to: (1) determine how the levels of physical activity and sedentary behaviour change and track between the ages of 5-6 years and 8-9 years, and (2) explore associations between changes in physical activity and sedentary behaviour from ages 5-6 to 8-9 years, and adiposity at 8-9 years.

It was discovered that both MVPA and total physical activity levels decreased throughout this period of middle childhood. The proportion of children meeting the UK's MVPA recommendations fell from 48% (55% of boys, 40% of girls) at 5-6 years to 27% (34% of boys, 19% of girls) at 8-9 years. Total sedentary time increased by 77 minutes between these ages. Total physical activity and the subjectively measured sedentary behaviours tracked at moderately strong levels. In contrast, the amount of time a child spent in MVPA at 5-6 years only weakly correlated with the amount of time they spent in MVPA aged 8-9 years.

In fully adjusted models, a decrease in MVPA and an increase in TV viewing time were the only two behaviours that were significantly associated with an increase in adiposity. A decrease in MVPA was associated with all four measures of adiposity. When gender differences were considered, these associations between MVPA and adiposity only remained significant in girls. In the fully adjusted models conducted on the overall sample, the only measure of adiposity that an increase in TV viewing time was significantly associated with, was an increase in BMI z-score.

5.2 Comparison with previous studies

5.2.1 Change in physical activity and sedentary behaviour

In this investigation, overall physical activity decreased and overall sedentary time increased, and boys were consistently found to be more active than girls. These are in accord with findings from previous studies(18,48,52-55,57-59,142,201). Most past investigations, despite focusing on children slightly older than those in the WAVES study, reported rates of change in physical activity and sedentary behaviour that are broadly similar to those presented in this thesis. A review which included 10 longitudinal studies objectively measuring changes in total sedentary time between childhood and adolescence, reported a weighted mean increase in sedentary time of 30 minutes/day/year(84). In this study the observed rates of increase in sedentary time were 35 minutes/day/year for boys and 29 minutes/day/year for girls. A pooled analysis of 26 studies examining changes in physical activity between childhood and adolescence (10-19 years), produced a mean decline in physical activity of 7.0% per year(202). The analyses presented in this thesis produced a slightly larger weighted mean decrease in MVPA – 8.6% per year for boys and 11.1% per year for girls. This could suggest that physical activity decreases at a faster rate in middle childhood compared to adolescence. However, this slight difference could also be due to the fact that 22 of the 26 studies included in the pooled analysis used a self-reported measure of physical activity, compared with the use of objective data in this investigation(202).

The three data collection points in this study enabled differences in the changes in physical activity and sedentary behaviour between baseline and follow-up 1, and follow-up 1 and follow-up 2 to be compared. This revealed an unexpected change between baseline (age 5-6 years) and follow-up 1 (7-8 years), when MVPA levels increased and total sedentary time decreased. Changes in these directions in children of this age have not previously been found, which could be explained by previous studies not examining children within this narrow age range. These changes may have arisen as a result of children participating in more structured MVPA activities as they become more physically able. However, when they are older still, there may be more of a focus on academic learning and thus more sedentary time within their day. It is also possible that this finding could be an artefact, caused by baseline and follow-up 1 measurements being taken at different times of year.

5.2.2 Tracking of physical activity and sedentary behaviour

Exploring the tracking of behaviours enables determination of when children settle into patterns of physical activity and sedentary behaviour. Previous investigations have generally found that physical activity tracks less well than sedentary behaviour, with physical activity tracking at a low to moderate level(48,61,63,203-206) and sedentary behaviour usually being shown to track at a moderately strong level(48,62,63,204,206). The results presented in this thesis generally agree with these previous investigations. The parent-reported sedentary behaviours all tracked at moderately strong levels. However, there was a large discrepancy between the tracking of total physical activity and that of MVPA, with total physical activity tracking at a moderately strong level and MVPA tracking only weakly. This suggests that the amount of light physical activity that children carry out is more stable throughout middle childhood compared with the more vigorous physical activity constructs. This could be caused by children adjusting to a more highly structured and academically focused school routine, which happens regardless of their tendency to carry out MVPA.

The tracking of MVPA shown in this study (correlation coefficient 0.29), was at the lower end of the range reported in other studies, with correlation coefficients between 0.30 and 0.60(48,61,203,207-211). This slightly lower degree of tracking could reflect the socioeconomically and ethnically diverse sample of children, as covariates are unable to be adjusted for with correlation coefficients. When the socio-demographic characteristics of children who maintained ≥60 minutes/day of MVPA between baseline and follow-up 2 were compared with children who carried out ≥60 minutes/day of MVPA at baseline but did not maintain this level, South Asian children were significantly less likely to continue with this level of MVPA at follow-up 2. This could mean that the tracking of MVPA in South Asian children is lower compared with children from other ethnic groups. Most similar studies have been conducted in predominantly White populations, and this could therefore be the reason for higher levels of MVPA tracking found in these studies(48,203,207,208,211).

TV viewing time has been shown to be one of the most stable behaviours during childhood, and the results in this thesis agree with this(53,62,205). Both of the tracking methods used for this thesis showed that the sedentary behaviours of TV viewing, computer and video-game use and craft all tracked at moderately strong levels. This adds evidence to suggest that these sedentary behaviours are fairly well entrenched by middle childhood, and are more stable when compared with MVPA.

5.2.3 The association between change in physical activity levels, and adiposity in childhood

Comparisons of the different associations that the change in physical activity of varying intensity have on overweight/obesity in children have rarely been examined. Of those studies that have been conducted, results suggest that there may be a dose-response relationship, with change in the more vigorous components of physical activity having a stronger association with adiposity, compared with change in light physical activity and total physical activity(77,212). The more vigorous components of physical activity have also been shown to have a stronger association with adiposity compared with lighter forms in studies that measured physical activity at just one point in time(75,76,213,214). This thesis considered the different associations of changes in total physical activity and MVPA, and the results support those from previous investigations. A decrease in MVPA, rather than a reduction in total physical activity, was significantly associated with an increase in most adiposity measures. The reason why a decrease in MVPA has a stronger impact on adiposity than a decrease in total physical activity is not clear. However, it is known that after MVPA is carried out, resting energy expenditure is increased for a sustained period of time(215). Also, when physical activity is conducted, rates of fat oxidation are increased which results in lowered abdominal adiposity(215-217). It is plausible that physical activity of higher intensity has a greater impact on increasing fat oxidation rates compared with lower levels of physical activity. Furthermore, a previous investigation provided evidence to suggest that cardiovascular fitness (as opposed to energy expenditure through physical activity) is the construct that is associated with decreases in adiposity(218). Another study concluded that cardiovascular fitness is a modifier in the relationship between physical activity and weight(219). Cardiovascular fitness is more likely to be influenced by the amount of MVPA that a child participates in rather than total physical activity, which could also help explain the results reported in this thesis.

Gender differences in the associations between change in physical activity and adiposity were considered in the investigation by Basterfield et al(77), which found that the association is stronger in boys than girls. Investigations that used a measure of physical activity from a single time-point, have also usually shown that the association between physical activity and adiposity is stronger in boys(70). However, this study's results show the opposite, with a decrease in MVPA being associated with all four measures of adiposity in girls, but no significant findings between a decrease in MVPA and adiposity being found in boys. Reasons for this are unlikely to be related to sample size, as there were similar numbers of girls and boys. This finding is also unlikely to have appeared as a result of greater decreases in MPVA throughout the study period in girls. Girls did decrease their MVPA from baseline to follow-up 2 at a slightly greater rate compared with boys – a decrease of 7.4 (SD=1.55) minutes/day/year for girls and 6.7 (SD=1.45) minutes/day/year for boys. However, this difference was non-significant. It is a possibility that the energy expenditure component of the energy balance equation is more important in girls than boys. It is not fully understood why the longitudinal study conducted by Basterfield et al which was carried out in the UK, on 403 children between the ages of 7-9 years, found that a decrease in MVPA was associated with an increase in adiposity (measured by BMI z-score and fat mass index), in boys but not girls(77). Physical activity was measured objectively using an Actigraph accelerometer over a 7 day period. The children in this previous study had lower levels of MVPA at both baseline and follow-up (26 minutes/day at baseline and 24 minutes/day at follow-up versus 72 minutes/day at baseline and 53 minutes/day at follow-up in this study)(77). This could suggest that at lower levels of physical activity, a decline in MPVA is more strongly associated with adiposity in boys, and at higher levels more strongly associated with adiposity in girls. However, this would need further exploration.

5.2.4 The association between change in sedentary behaviours, and adiposity in childhood

In fully adjusted models, an increase in TV viewing time was significantly associated with an increase in BMI z-score. No significant association was found between an increase in total sedentary time or an increase in the other sedentary behaviours, and adiposity. Past research generally supports these findings(66,82). Numerous theories could explain why TV viewing is the only measure of sedentary behaviour that is associated with adiposity. These include a lowered resting energy expenditure whilst watching TV; research has shown that when an individual watches TV, energy expenditure decreases to a level lower than when doing nothing at all(220). Additionally, whilst children watch TV there is often an increase in food consumption(221-223). Caloric intake can also be increased through exposure to advertisements promoting unhealthy foods(224). It has previously been proposed that a further way in which TV viewing increases adiposity is via the replacement of physical activity with TV viewing(225). In this investigation, when changes in total physical activity were adjusted for in analyses, the significant association between increased TV viewing and adiposity remained in boys but not girls. This suggests that the replacement of physical activity with TV viewing is an unlikely mechanism for weight gain in boys, but is likely to be occurring in girls. The null relationships obtained between an increase in the other screen activities (video-gaming and computer use) and adiposity could be in part explained by the concept that video-gaming and computer use, unlike TV viewing, are not hands-free activities. This means that there are limited opportunities for snacking(82). Another possibility is that video-gaming and computer use do not cause as much of a reduction in resting energy expenditure compared with TV viewing(82,226). Nowadays, there are many active video-games, such as those that are played on the Nintendo Wii. Playing these active video-games has been shown to produce a higher level of energy expenditure compared with watching TV(227). It is felt that due to these differing associations with adiposity, future investigations should consider TV viewing, video-gaming and computer use as separate variables, rather than combining them all as one 'screen time' variable, which has often been the case in previous research.

It is unclear why the only measure of adiposity that showed a significant association between an increase in TV viewing and adiposity in the overall sample, was BMI z-score. It implies that TV viewing has more of an impact on increasing overall weight compared with subcutaneous and abdominal adiposity. However, when gender differences were considered, an increase in TV viewing in boys was significantly associated with an increase in waist circumference z-score. In girls, a significant association between increased TV viewing and BMI z-score was present, although this effect was attenuated in the fully adjusted model. It is possible that there are gender differences in the development of overweight as a result of TV viewing, which lead to a greater increase in central adiposity in boys and overall weight in girls. The inconsistencies between the associations found with the different measures of adiposity suggest that each measure of adiposity needs to be treated as an individual entity and examined separately in future research.

5.3 The implications of findings for future intervention programmes

The results presented in this thesis suggest that future childhood obesity prevention programmes focusing on physical activity levels, should aim to increase the amount of MVPA that children carry out, instead of trying to increase total physical activity. The Scottish Childhood Overweight Treatment Trial (SCOTT) successfully increased the amount of light physical activity (but not the MVPA) undertaken in a sample of 5-11 year old children(228). It did not produce any corresponding decrease in BMI levels, which provides additional evidence to support the targeting of more vigorous components of activity over light physical activity, as well as targeting other weight-related behaviours, such as dietary intake. The weak tracking of MVPA throughout middle childhood found in this study implies that MVPA is not a stable behaviour at this age and therefore a population approach should be utilised, aiming to increase the MVPA of all children of this age. A life course approach would also be beneficial in order to maintain MVPA improvements into adulthood. The results from the analyses in this thesis, suggest that girls should be particularly targeted because girls consistently showed lower levels of MVPA compared with boys, but also because a decrease in MVPA only showed significant associations with adiposity in girls. However, conflicting results with previous studies regarding gender differences in the associations between MVPA and adiposity merits further exploration into these differences, before gender-targeted interventions are introduced(70,77).

These results also suggest that intervention programmes aiming to reduce overweight/obesity through a reduction in sedentary time should primarily focus on TV viewing time. There is not currently enough evidence to connote that a reduction in the time a child spends video-gaming or on the computer will have any impact on their weight. In contrast to MVPA, TV viewing has been shown to track at a moderately strong level, implying that this behaviour is more stable during middle childhood. Intervention programmes will need to develop effective ways of losing this stability in 'high risk' groups of children who carry out the most TV viewing.

Furthermore, as previously discussed in Section 5.2.1, in this investigation physical activity levels were the highest and total sedentary time was the lowest when the children were aged 7-8 years. Future intervention studies targeting children in the middle childhood years, could target children of this age. This would mean that a greater emphasis could be placed on maintaining higher MVPA and lower sedentary levels rather than trying to significantly modify them.

5.4 Areas that future research should focus on

As previously stated, this investigation found significant associations between a decrease in MVPA and adiposity, and an increase in TV viewing time and adiposity. However, the clinical significance of these associations is largely unknown. A decrease in BMI z-score of 0.25 is associated with a reduction of approximately 0.5 Kg of body weight in children of primary school age(101) and clinically detectable benefits in obese children (e.g. reductions in insulin, total cholesterol and low density lipoprotein cholesterol)(229). In these analyses on the overall sample, a decrease in MVPA of 30 minutes/day was associated with an increase in BMI z-score of 0.08. Seven percent of the sample decreased their MVPA by 90 minutes/day or more, which would produce an increase in BMI z-score of 0.24 – approximately at the level where clinically detectable benefits have been found to occur(101,229). A 1 hour/day increase in TV viewing in this investigation was associated with an increase in BMI z-score of 0.06. Only 2% of children increased their TV viewing by 4 hours/day or more, which would give a clinically significant increase in BMI z-score. Two previous reviews concluded that associations between TV viewing and adiposity are unlikely to be of clinical significance(82,83). However, more research is required in order to evaluate whether there are any observable health benefits with decreases in BMI z-score that are lower than this. Furthermore, the level for a clinically detectable change in waist circumference z-score, skinfold thicknesses and BF% is yet to be determined in children. Finally, it is possible that in isolation, decreasing TV viewing or increasing MVPA may not have a clinically significant effect, but as part of a multifaceted intervention, it could contribute towards a clinically significant reduction in adiposity over time.

This thesis used two physical activity constructs in analysis – MVPA and total physical activity. MVPA was the construct used to represent higher intensity of activity because the UK's physical activity recommendations are based on MVPA(2). However, future work could look into the separate associations that vigorous physical activity and moderate physical activity have on adiposity. This would help inform both future intervention studies and public health recommendations relating to physical activity. Vigorous physical activity when compared with moderate physical activity, may have more impact on improving cardiorespiratory fitness, which as described in Section 5.2.3 has been found to be a modifier in the relationship between physical activity and weight(219). Limited cross-sectional studies have suggested that the most vigorous component of activity may have a stronger relationship with adiposity than moderate activity(76,78). However, longitudinal research is required to support these findings.

South Asian children in this sample were significantly less likely to maintain ≥60 minutes/day of MVPA throughout middle childhood compared with children from other ethnic groups. This implies that there are differences in the tracking of physical activity between children of different ethnic groups. This thesis did not consider these differences in detail. This should be a focus for future research as the findings would help to determine which ethnic groups should be targeted.

Finally, investigation into comparisons between week days and weekends in the changes in physical activity and sedentary behaviour was beyond the scope of this thesis. Two studies have considered week day and weekend physical activity and sedentary behaviour levels separately(54,57). Both of these found differences between the two parts of the week. Both physical activity and sedentary behaviour were found to be lower on weekends(57). In addition, between the ages of 9-10 years and 13-14 years, MVPA has been shown to decline more on weekends compared to week days(54). Future research could therefore explore the association between a decrease in MVPA and adiposity separately for week days and weekends. This information could be used to inform the design of interventions targeting physical activity and sedentary behaviour.

5.5 Strengths and limitations

5.5.1 Strengths

This study included a large sample of ethnically and socioeconomically diverse children. The diverse sample increases the generalisability of the results to all children in the UK. It has previously been documented that most of the past studies exploring associations between physical activity and sedentary behaviour, and weight in children have had very small sample sizes(70). Of the 7 longitudinal studies focusing on objectively measured physical activity in the review by Jiménez-Pavón et al(70), only one had a sample size of over 1000 children(230). It has been proposed that many of the smaller studies may have obtained a null relationship due to being underpowered(66,68,69). Overweight/obesity develops as the result of small energy imbalances over a period of time. It therefore follows that small changes in the measures of adiposity are required to be identified. A large sample size is more likely to provide the power needed to be able to do this.

This study followed children throughout the middle childhood years (from ages 5-6 years to 8-9 years). The physical activity and sedentary behaviour of this age group has currently been very underexplored, but it is essential to understand more about weight related behaviours and how they change in this period of life, given the increases in adiposity that occur at this time(38,51,231). It is also a key transition period where children move from the relatively unstructured home environment to a scheduled school routine. Middle childhood is also when children begin to socially interact with each other which has an impact on decisions regarding physical activity and sedentary behaviour(232). A confounder that is difficult to control for when examining changes in physical activity and sedentary behaviour is individual growth and maturation. However, it is felt that the small age gap between baseline (5-6 years) and follow-up 2 (8-9 years) in this study's sample will reduce these confounding effects. Furthermore, pubertal growth is likely to have the largest confounding effects, which should be minimal in this sample of mostly pre-pubertal children.

One of the main strengths of this study is its longitudinal design. The vast majority of previous research has been cross-sectional in nature(21,66,70,82). The use of follow-up measures of adiposity as outcome variables in this investigation allowed elimination of reverse causality, which cross-sectional studies are unable to do(220). It is possible that associations found in previous cross-sectional studies are due to overweight/obese children being less likely to participate in activity and more likely to be sedentary due to fears about being teased during activity or because being overweight makes activity more challenging and painful(66). It has previously been proposed that overweight children have less social interaction with their peers and so are less likely to carry out active play with friends(83).

Physical activity and total sedentary time were measured objectively using a combined accelerometer and heart rate monitor. Many previous investigations used a subjective measure of the time each child spends undertaking physical activity and sedentary behaviours. For example, only 5 of the 17 longitudinal studies included in a review of the literature on the association between physical activity and weight in children, used an objective measure of physical activity(66). In addition, a 2014 review exploring longitudinal associations between the change in sedentary behaviour and change in adiposity, only managed to identify three studies which had used an objective measure of sedentary time(84). Subjective measures are usually in the form of self-reports completed by the child or their parents, and are subject to a number of inaccuracies including social desirability bias.

Four different continuous adiposity measures were analysed to increase the validity of findings. It has previously been put forward that by using a continuous measure of adiposity rather than a categorical one, it is easier to examine the entire range of adiposity in children(70,233).

Finally, the analyses conducted for this thesis were able to determine the independent relationships between physical activity and sedentary behaviour, and adiposity. This was through adjustment for a change in total physical activity in the analyses examining the association between increased sedentary behaviour and adiposity, and adjustment for a change in total sedentary time in the analyses examining the associations between decreased physical activity and adiposity. To date, this has only been done by a handful of studies(75-77,94).

5.5.2 Limitations

It is acknowledged that the work presented in this thesis has some limitations. Firstly, the time spent carrying out the individual sedentary behaviours was measured subjectively, through a parental questionnaire. This was subject to responder bias. Children with a completed questionnaire were more likely to be White British ($p<0.001$) and of a higher socioeconomic status ($p<0.001$) than those without a completed questionnaire. This makes conclusions relating to the sedentary behaviours less applicable to the ethnically and socioeconomically diverse sample of the UK. However, no significant differences in BMI z-score, age and gender were found between children with and without questionnaire data. The questionnaire was anonymous, but it may still have been subject to social desirability bias as most parents are aware that children should not spend too long carrying out sedentary behaviours, such as TV viewing and video-gaming. Parents may also not know exactly how long their child spends carrying out each sedentary behaviour that was measured, particularly when the children get older. Previous research has found very limited correlation between parental reports of TV viewing and TV viewing determined via home observations carried out with the use of video tape(234,235).

Similar to most longitudinal studies, attrition bias may have also affected these results. Participants were more likely to drop out of the study if they were African Caribbean (p=<0.001) and from a lower socioeconomic status (p=<0.001). Attrition bias has the impact of making the conclusions less generalisable to these socio-demographic groups. It is known that African Caribbean children and children from the lowest socioeconomic groups carry out the most sedentary behaviour(18,19), and that African Caribbean girls carry out less MVPA when compared with White British girls(19). It is therefore likely that the relatively higher follow-up loss of children from African Caribbean groups and children from the lowest socioeconomic subgroup would have impacted on the physical activity and sedentary behaviour trajectories presented in this thesis. It is probable that the reduction in physical activity and the increase in sedentary behaviour seen in children over the study period would have been even greater if follow-up had been complete.

It is possible that the effects of residual confounding are a limitation of this work. This has been documented as a problem in many previous studies(66). Despite adjustment for a large number of important socio-demographic covariates, the confounding effect may not have been fully removed due to incomplete adjustment. For example, the effect of diet was not adjusted for which is an important determinant of energy balance and therefore adiposity. The measure of diet in the WAVES study was a snapshot of energy intake over a 24-hour period(236). Therefore changes in the usual energy intake over the study period could not be accurately estimated from the data collected.

It is difficult to predict the impact of not adjusting for energy intake during analysis because the relationship between physical activity, energy intake and adiposity is complex and not fully understood. It is not a simple energy balance equation(237). There is research evidence to suggest that individuals who carry out a lot of physical activity have a higher metabolic rate(238), meaning that they will have a greater energy expenditure for a given energy intake. There is also conflicting research regarding whether physical activity is inversely related to energy intake (i.e. individuals who carry out more physical activity have lower calorie diets)(239), or whether physical activity and energy intake are unrelated(240,241). If the former is true, then adjustment for energy intake in the analyses would be likely to attenuate the association between physical activity and adiposity. However, if the latter is true, then adjustment for energy intake would be unlikely to have any significant effect on results.

Regarding the association between TV viewing and adiposity, there is evidence to show that children consume more energy dense foods whilst watching TV(221-223). Therefore, it may be that a combination of sedentary behaviour and increased energy intake leads to increased adiposity. If this is the case, adjustment for energy intake during analysis would be likely to attenuate the association between TV viewing and adiposity.

Finally, the physical activity and sedentary behaviour of children in the UK shows seasonal variation, with physical activity being highest in the summer and lowest throughout the winter(242). Baseline, follow-up 1 and follow-up 2 data were all collected at different times of the year which is likely to have had an impact on physical activity and sedentary behaviour levels. Baseline measurements were collected during the Spring and Summer months, when physical activity is typically highest. In contrast, follow-up 1 and follow-up

2 measurements were taken during the Autumn/Winter and Winter/Spring respectively. This is likely to have caused the decrease in physical activity between baseline and follow-up 1, and baseline and follow-up 2, to be greater than if physical activity had been measured at the same time of year. Adjustment during analyses for the month that measurements were taken would have been unlikely to resolve this issue, as it is highly likely that the weather is the factor that influences children's physical activity the most, and no weather data were collected.

It has also previously been shown that the physical activity of children tracks at a weaker level on weekends compared to week days(97,243,244). In this study, the children wore the Actiheart monitor for five days, which included two weekend days. This overrepresentation of weekend days could have caused the tracking of activity to appear weaker than it in fact is.

5.6 Conclusions

To conclude, this thesis found that a decrease in MVPA between the ages of 5-6 years and 8-9 years was associated with an increase in BMI z-score, waist circumference z-score, BF% and skinfold thicknesses. When gender differences were considered, these associations were present in girls but not boys. It also found that an increase in TV viewing during this period of middle childhood was associated with an increase in BMI z-score. Therefore future intervention studies aiming to reduce childhood overweight and obesity, may be best placed focusing on MVPA and TV viewing. The weak level of tracking of MVPA throughout middle childhood suggests that an approach aiming to increase the MVPA of all children would be most effective, whereas the stronger tracking shown with

TV viewing implies that TV is a more stable behaviour and that work needs to be done into ways of eradicating this stability in children who show high levels of TV viewing.

6: APPENDICES

7: REFERENCES

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